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# FOURFIT—A COMPUTER CODE FOR DETERMINING EQUIVALENT NUCLEAR YIELD AND PEAK OVERPRESSURE BY A FOURIER SPECTRUM FIT METHOD

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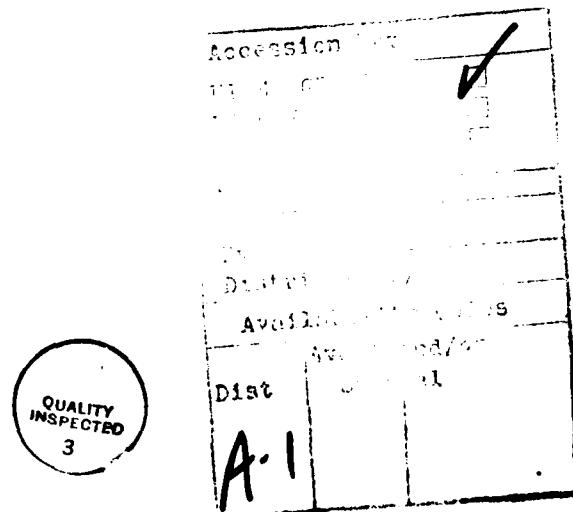


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## SUMMARY

A computer code for determining the equivalent nuclear pressure and yield of airblast simulation records is presented. The code was written to automate a previously developed graphical fitting technique known as FOURFIT. FOURFIT determines a best fit nuclear waveform to airblast simulation data by comparing the Fourier amplitude spectra of the data with spectra for ideal nuclear waveforms. This report also presents results of the use of this code, also named FOURFIT, and a companion code, FOURPLT, which permits the results to be plotted. Fits to record traces from two separate simulation events are compared to previously published results which were determined using the graphical version of the technique.



## PREFACE

The analysis presented herein was performed as part of work conducted during the period May 1983 to February 1984, on Contract DNA001-82-C-0098/P00002, Investigation of Scaling, Simulation and Associated Requirements for the STP 3 Combined Effects Program.

Conversion factors for U.S. customary  
to metric (SI) units of measurements.

To Convert From	To	Multiply By
angstrom	meters (m)	1.000 000 X E -10
atmosphere (normal)	kilo pascal (kPa)	1 013 25 X E +2
bar	kilo pascal (kPa)	1.000 000 X E +2
barn	meter <sup>2</sup> (m <sup>2</sup> )	1.000 000 X E -28
British thermal unit (thermochemical)	joule (J)	1.054 350 X E +3
calorie (thermochemical)	joule (J)	4 184 000
cal (thermochemical)/cm <sup>2</sup>	mega joule/m <sup>2</sup> (MJ/m <sup>2</sup> )	4.184 000 X E -2
curie	giga becquerel (GBq)	3.700 000 X E +1
degree (angle)	radian (rad)	1.745 329 X E -2
degree Fahrenheit	degree kelvin (K)	$t_K = (t^{\circ}F + 459.67)/1.8$
electron volt	joule (J)	1.602 19 X E -19
erg	joule (J)	1.000 000 X E -7
erg/second	watt (W)	1.000 000 X E -7
foot	meter (m)	3.048 000 X E -1
foot-pound-force	joule (J)	1.355 818
gallon (U. S. liquid)	meter <sup>3</sup> (m <sup>3</sup> )	3.785 412 X E -3
inch	meter (m)	2.540 000 X E -2
jerk	joule (J)	1.000 000 X E +9
joule/kilogram (J/kg) (radiation dose absorbed)	Gray (Gy)	1.000 000
kilotons	terajoules	4.183
kip (1000 lbf)	newton (N)	4.448 222 X E +3
kip/inch <sup>2</sup> (ksi)	kilo pascal (kPa)	6.894 757 X E +3
ktap	newton-second/m <sup>2</sup> (N·s/m <sup>2</sup> )	1.000 000 X E +2
micron	meter (m)	1.000 000 X E -6
mill	meter (m)	2.540 000 X E -5
mile (international)	meter (m)	1.609 344 X E +3
ounce	kilogram (kg)	2.634 952 X E -2
pound-force (lbs avoirdupois)	newton (N)	4.448 222
pound-force inch	newton-meter (N·m)	1.129 848 X E -1
pound-force/inch	newton/meter (N/m)	1.751 269 X E +2
pound-force/foot <sup>2</sup>	kilo pascal (kPa)	4.788 026 X E -2
pound-force/inch <sup>2</sup> (psi)	kilo pascal (kPa)	6.894 757
pound-mass (lbm avoirdupois)	kilogram (kg)	4.535 924 X E -3
pound-mass-foot <sup>2</sup> (moment of inertia)	kilogram-meter <sup>2</sup> (kg·m <sup>2</sup> )	4.214 011 X E -2
pound-mass/foot <sup>3</sup>	kilogram/meter <sup>3</sup> (kg/m <sup>3</sup> )	1.601 846 X E +1
rad (radiation dose absorbed)	*Gray (Gy)	1.000 000 X E -2
roentgen	coulomb/kilogram (C/kg)	2.579 760 X E -4
shake	second (s)	1.000 000 X E -8
slug	kilogram (kg)	1.459 390 X E +1
torr (mm Hg, 0° C)	kilo pascal (kPa)	1.333 22 X E -3

\*The becquerel (Bq) is the SI unit of radioactivity; 1 Bq = 1 event/s.

\*\*The Gray (Gy) is the SI unit of absorbed radiation.

A more complete listing of conversions may be found in "Metric Practice Guide E 380-74,"  
American Society for Testing and Materials.

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## SECTION 1

### INTRODUCTION

The development and application of a Fourier domain technique for estimating the equivalent nuclear yield ( $W$ ) and peak overpressure ( $P_{so}$ ) of airblast simulation records are presented in References 1 and 2. The estimates are made graphically by comparing the Fourier amplitude spectra of the data records to the amplitude spectra of ideal nuclear airblast curves. Additionally, the methodology includes a means for identifying, through low pass filtering of the data, a "fidelity frequency" below which the data and the ideal curves are in good agreement.

The technique, called FOURFIT, has several advantages. These include:

- The Fourier amplitude representation of the data provides considerable insight into the frequency content of the data.
- The method provides consistent results for the values of  $W$  and  $P_{so}$  estimated for multiple records from the same event. Other methods give more scattered estimates (see Ref. 3).
- The technique is quick and easy to perform.
- FOURFIT can be performed graphically.

Despite the advantage of the physical insight provided to an analyst through graphical fitting, an alternative "automatic" fitting approach is desirable to enable quicker turn-around time for the results of large numbers of data records.

This report documents such a method. A computer program, FOURFIT, has been written which seeks to minimize the sum of the squares of the difference between the data Fourier amplitude and the amplitudes of candidate ideal nuclear fits. The amplitudes for the candidate fits are determined by an equation, parametic in  $P_{SO}$  and  $W$ , which describes the spectra for the Speicher-Brode nuclear overpressure (Ref. 4). In addition, the program provides an estimate of the low pass fidelity frequency mentioned above.

Section 2 of this report reviews the background of the FOURFIT technique. Section 3 discusses the structure and use of the computer code and its algorithm for determining best fit equivalent yield and pressure. Section 4 presents some initial results determined by the code. Section 5 discusses some considerations into the effects of high pass and band pass filtering of airblast simulation data. Finally, Section 6 presents conclusions and recommendations.

## SECTION 2

### THE FOURFIT TECHNIQUE

#### 2.1. REASONS FOR FOURFIT ANALYSIS

High explosive simulations of nuclear airblast often lead to inherent differences between the simulated environment and the ideal nuclear environment being modeled. For example, high frequency spikes in the early time portion of High Explosive Simulation Technique (HEST) simulated airblast records, as seen in Figure 1, are not normally present in actual nuclear overpressure pulses.

High frequency spikes in the HEST waveform and other simulation pressure history differences pose difficulties when fitting these records with an ideal nuclear pulse in the time domain. Time domain fitting methods and, indeed, the acceptance of HEST as a useful simulator, assume that the high frequencies of the HEST waveform do not drive the response of systems of interest. Yet time domain fitting is complicated by the fact that high frequencies and low frequencies are superimposed in that domain. This complication is especially difficult in the interpretation of HEST peak overpressure because the absolute peak overpressure is associated with a high frequency spike.

However, when viewed in the frequency domain, the relative importance of waveform differences is revealed. The Fourier transform unfolds the various frequency contributions to the pressure history and allows the analyst to fit those spectral portions of a record which dominate the power in the waveform. Use of the Fourier amplitude spectrum for fitting purposes thus provides for a more accurate ideal nuclear fit to the simulation data than do time domain techniques.

## 2.2. DEVELOPMENT OF THE FOURFIT TECHNIQUE

The nuclear airblast pressure waveform satisfies the conditions for existence of the Fourier integral transform. That is,

- It contains a finite number of minima and maxima.
- It contains a finite number of discontinuities.
- The function is aperiodic.

Therefore, a measured airblast waveform may be Fourier transformed using a fast Fourier transform (FFT) based upon the integral discrete Fourier transform (DFT) as represented by equation 1 below.

$$H_c(n/N\Delta t) = T \sum_{k=0}^{N-1} h_c(k\Delta t) e^{-j2\pi kn/N} \quad (1)$$

where  $T$  = duration of the signal

$\Delta t$  = timestep between data points

$k, n$  = integer values and represent the periodicity of the time and the frequency functions, respectively.

The DFT represents a limited duration signal,  $h$ , as one period of an infinite periodic series summed over  $N$  samples of data and the subscript  $c$  above is used to denote an approximation caused by this truncation of the signal. The FFT computes a real portion and an imaginary portion of the Fourier transform,  $H$ . These portions, in turn, may be used to compute Fourier amplitude and phase. Figure 2 shows the Fourier amplitude representation of the pressure history for the HEST record of Figure 1.

To determine the nuclear representation of the simulation data, the Fourier spectrum computed for that data must be compared to the spectra computed for ideal nuclear waveforms. The studies of References 1 and 2 and the example presented in this section were based upon the "New Brode"

description of the nuclear waveform (Ref. 5). However, a later study (Ref. 3) and the FOURFIT code discussed in following sections of this report are based upon the more recent Speicher-Brode formulations (Ref. 4). Figure 3 presents the "New Brode" pressure histories for several overpressures in scaled form. The scalars make the curves applicable for all yields.

#### 2.2.1. Estimation of Peak Pressure and Yield

A parametric review of Fourier amplitude spectra and dimensional consideration of the DFT and the Brode equations revealed the proper scaling parameters for the airblast Fourier amplitude spectra. It was found that Fourier amplitude scales by the product of peak overpressure and the cube root of the yield (i.e.,  $(P_{so} \times w^{1/3})^{-1}$ ). Furthermore, Fourier frequency was found to scale by the cube root of the yield (i.e.,  $w^{1/3}$ ). Figure 4 illustrates a set of surface burst Brode Fourier amplitude spectra in scaled form.

The normalization of the ideal nuclear spectra provides the basis for the implementation of the FOURFIT technique. The analyst first notes that the slope of each Brode spectrum is inversely proportional to the value of peak overpressure. That is, as  $P_{so}$  increases the spectra flatten as the amount of power carried within the higher frequencies increases relative to the power in the low frequency regime. With this in mind, the analyst makes an initial estimate of the data equivalent peak pressure by comparing the data spectrum to the Brode spectra. The ideal spectrum which best compares to the data defines the initial estimate of  $P_{so}$ . The corresponding yield is determined as guided by the scaled amplitude plots. The steps discussed below and illustrated by Figure 5

utilize those scaled plots as an overlay to the data to find the final fit. The technique will be illustrated using the HEST spectrum shown in Figure 2.

In the first step, a comparison of the data spectrum to the Brode spectra indicates a peak pressure of about 3 megaPascals to be a reasonable estimate. Next, note that since amplitude scales by  $(P_{so} \times W^{1/3})^{-1}$  and frequency scales by  $W^{1/3}$ , the amplitude scalar is exactly  $P_{so}$  times the frequency scalar. With  $P_{so}$  already estimated, the problem is reduced to finding one unknown, namely, the yield. Graphically, this is performed by overlaying the spectral data onto the ideal spectra such that, at equal locations on the respective frequency axes

$$\text{i.e., } F_B \times W^{1/3} = F_D \quad (2)$$

the amplitude axes are shifted by a ratio equal to the estimate for  $P_{so}$

$$\text{i.e., } P_{so} \times (A_B / (P_{so} \times W^{1/3})) = A_D \quad (3)$$

or, in the example, a vertical shift by a factor of about 3. The subscripts B and D refer to the Brode and the data, respectively. Since the plots are in the logarithmic domain any shift represents a constant multiplier.

Similarly, the scalar  $W^{1/3}$ , as a constant multiplier, can be represented by a shift. This shift is defined such that, since  $W^{1/3}$  is the same multiplier on both axes, only a shift along a line of slope equal to 1:1 will maintain an equal axis shift. Furthermore, the shift occurs along a line of -1 slope since the actual scalars are  $(W^{1/3})^{-1}$  for amplitude and  $W^{1/3}$  for frequency. With the shift thus defined, it simply is left to perform this shift until the data spectrum properly

interpolates the Brode spectra to a location representing the value for peak overpressure chosen for the fit (i.e., between the 2 MPa spectrum and the 5 MPa spectrum). The resulting pressure/yield pair is then computed by "unscaling" the overlay. That is, the comparisons of the respective frequency and amplitude axes for the data and for the normalized Brodes, as shown in the equations below, will result in estimates of the two variables ( $P_{SO}$  and  $W$ ).

$$\frac{F_f}{F_B \times W^{1/3}} = (W_f^{1/3})^{-1} \quad (4)$$

and

$$\frac{A_f}{[A_B / (P_{SO} \times W^{1/3})]} = P_{SO} \left( \frac{F_f}{F_B \times W^{1/3}} \right)^{-1} \quad (5)$$

The subscript f refers to the fit to the data.

The results for the example are shown on Figure 5 and the yield is computed below.

$$\frac{3300 \text{ Hz } KT^{1/3}}{200 \text{ Hz}} = W_f^{1/3}$$

or

$$W_f = (1.64 \text{ KT}^{1/3})^3$$

$$= 4.44 \text{ KT}$$

Also, the calculation below confirms the amplitude scale using the peak pressure (2.78 MPa) and the yield (4.44 KT) defined for the fit.

$$\frac{.1 \text{ MPa-sec}}{.0218 \text{ sec/KT}^{1/3}} = (2.78 \text{ MPa})(4.44 \text{ KT})^{1/3} \quad (7)$$

A Brode overpressure history and associated impulse history and Fourier amplitude spectrum are then calculated for these values of peak

overpressure and yield. The three representations of this signal can now be compared to those of the data to refine the fit. A need for slight adjustment to the fit is expected considering the graphical nature of the technique.

The amplitude spectrum fit procedure is repeated to improve the frequency and time fits. The adjusted estimates for the example define the pressure to be 2.95 MPa and the yield to be 5.05 KT. Figures 6 to 8 show the pressure and impulse histories and the amplitude spectrum of the Brode defined by these final values compared to the respective representations of the record. This is an acceptable fit and thus will be carried to the next step of the process.

### 2.2.2. Estimation of Fidelity Frequency

It may be noted from Figure 4 that the low frequency regime of the nuclear airblast carries significantly more power than is carried by the high frequencies. Furthermore, most systems of interest in airblast simulations respond to low frequency input. This section describes a methodology which, through low pass filtering, quantitatively defines a frequency cutoff where systems sensitive to frequencies below that cutoff experience the loading as defined by the FOURFIT results in the preceding paragraphs. This frequency is identified as the fidelity frequency for the record since it defines a limit above which the fidelity of the simulation relative to the prototype degrades.

Identification of a fidelity frequency makes use of the fact that most of the power in the airblast signal exists in the low frequencies. This suggests that although low pass filtering of the signal may alter the exact shape of the waveform, it should have limited effect

on the total power delivered. This is illustrated in Figures 9 and 10 for a Brode pulse. In Figure 9 it is seen that as the cutoff frequency is lowered, the peak of the filtered pressure history decreases. However, this peak reduction is accompanied by a broadening of that peak. This suggests that the deliverance of power is only delayed, not diminished. This hypothesis is supported by noting that the total impulse of the filtered Brode (Fig. 10) is virtually unchanged.

The determination of fidelity frequency utilizes the relationships between peak attenuation and cutoff frequency. It was found that the filtered peaks of the data record show a similar trend versus the respective cutoff frequency. Fidelity frequency is identified by using this similarity and with an overlay technique similar to that used to determine  $P_{SO}$  and  $W$  using the Fourier amplitude spectra.

A plot of the data peak attenuation versus cutoff frequency is an overlay to the Brode peak attenuation curves (Fig. 11). Note that the filtered Brode peak is scaled by  $P_{SO}$  and that the Brode cutoff frequency is scaled by  $W^{1/3}$ . As illustrated in Figure 11 for the record of the example, the data attenuation plot is shifted the proper amount on the vertical axis and on the horizontal axis as defined by  $P_{SO}$  and by  $W$ , respectively. This allows that the data attenuation curve approaches and eventually merges into the attenuation curve for the equivalent value of  $P_{SO}$ . The merger of these curves defines the fidelity cutoff frequency (180 Hz for the example). Below this frequency the data record is similar to the equivalent Brode. Above this frequency, the data contains diversions from the Brode which, in effect, do not load systems sensitive only to frequencies below this cutoff. Figure 12 compares the filtered

data record to its filtered equivalent Brode for different cutoff frequencies. Note the excellent agreement between the data history and the Brode history at the 200 Hz (~180 Hz) cutoff.

Previous studies (Ref. 1, 2, 3) have shown that the FOURFIT technique provides consistent estimates of peak pressure and yield for multiple pressure records from the same event. In addition, the technique is graphical in nature and easy to perform. However, it is desirable that an alternative "automatic" fitting routine be available. The existence of a computer oriented fitting alternative would allow for more rapid analysis of airblast records and would be free of analyst bias. A computer program, FOURFIT, has been written to achieve this goal and is discussed in detail in the following section.

### SECTION 3

#### PROGRAM FOURFIT

Despite the advantages of performing the graphical FOURFIT technique described earlier, a quick "automated" version of the method was desired to provide rapid analysis of the typical airblast simulation record. Program FOURFIT was written to achieve this goal. Appendix A provides a listing of this code.

Program FOURFIT finds the best fit nuclear waveform for airblast data based upon a search to minimize the sum of the squares of the differences between the data Fourier amplitude spectrum and trial ideal spectra. The Fourier transform of the data is performed by a call to the International Mathematics and Statistics Library (IMSL) routine FFTRC (Ref. 6). IMSL is maintained on the Defense Nuclear Agency (DNA) CDC Cyber 176 computer on which FOURFIT was written. The ideal nuclear Fourier amplitudes for trial fits are computed by an equation, parametric in  $P_{SO}$  and  $W$ , which describes the amplitude spectra for a set of curves similar to those presented in Figure 4. The equation, however, describes the more recent Speicher-Brode fit to the nuclear overpressure waveform (Ref. 4) represented in scaled form in Figure 13. Scaled Speicher-Brode impulse histories and Fourier amplitude spectra are presented in Figures 14 and 15, respectively. A detailed description of the fitting program follows.

The program is run by reading an input deck (TAPE2) to define user options. Results are listed in output (TAPE6) and plotting information is written to TAPE48 to be plotted by FOURPLT, the accompanying plotting program.

### 3.1. INPUT VARIABLES

The main purpose of the program FOURFIT is to perform fits to surface burst airblast simulation data. The program compares data Fourier amplitude spectra to estimates of the Fourier amplitude spectra of the ideal nuclear represented by the Speicher-Brode pressure-time equation. However, the code is also set up to perform FFT analysis of the data without finding a fit, or to perform a FFT on a specific Speicher-Brode defined by a pressure/yield pair requested by the analyst. FOURFIT also computes the impulse history for either of these latter cases. Finally, the code is set up to perform a low pass Butterworth filter of either data or a Speicher-Brode at up to seven cutoff frequencies, specified by the user, per run.

The options mentioned above are to be chosen by the analyst and read from an input deck, TAPE2, assembled by that analyst. The contents of TAPE2 are summarized below. The code reads all input lines, including those not used in analysis, in all runs.

Line 1: NEPTS, IUNITS, JUNITS (Format 3I5)

The value for NEPTS is the number of points to be read from the data tape. The other variables in this line account for data input units. For IUNITS greater than zero, the code assumes that the pressure values are read in pounds per square inch and converts the data to megaPascals, the internal units of the code. For IUNITS less than zero, the data is assumed to be read in the program units. Furthermore, the program works in units of seconds for time and Hertz for frequency. JUNITS less than zero indicates an input time step consistent with this fact. For JUNITS greater than zero, the program assumes input in milliseconds and performs

the proper conversion. The value of these variables do not affect the calculation of a Speicher-Brode function.

Line 2: PSOI, WI (Format 2F5.2)

The meaning of these terms in line 2 differs depending on the program option (explained in line 3) chosen. For analysis of a data trace for its impulse and FFT or for filtering that data, without performing a fit, PSOI and WI are not used. However, for the case of fitting the data with a Speicher-Brode, these variables provide the "seeds" for defining the candidate fits. PSOI is the seed for peak overpressure in MPa and WI is the seed for nuclear yield in kilotons. A wide range about these seeds (plus and minus a decade for each) is tested and so they need not be exceptionally close to the final values. However, a good set of seeds may nominally be considered to be the event design pressure and yield. For cases in which only the Speicher-Brode will be analyzed, PSOI and WI are the peak overpressure and yield values, respectively, of the ideal waveform to be calculated.

Line 3: IOPT, IFILT (Format 2I5)

IOPT defines the program option to be run. IOPT equals 1 for performing the FOURFIT automated fitting routine. To simply integrate and FFT the data, IOPT equals 2. For IOPT equals 3, the code analyzes only the Speicher-Brode specified by PSOI and WI in line 2. The value for IFILT determines whether or not the pressure history is to be filtered. No filtering is done for IOPT equal to 2 or 3 if the value of IFILT is less than zero. A value of IFILT greater than zero for these same IOPT values performs a low pass Butterworth filter on the pressure history at the cutoff frequencies defined by FLO (line 4). For IFILT greater than

zero, neither impulse nor FFT calculations are performed. For IOPT equal to 1, IFILT may be any value.

Line 4: FL0(I), I=1,7 (Format 7F10.0)

FL0(I) are the low pass cutoff frequencies in Hertz used by the Butterworth filter. Up to seven filter levels, in any order, are allowed for options 2 and 3. For the number of filters, N, less than seven, FL0(N + 1) must be set to 0. Although option 1 does not utilize the IFILT value (line 3), it nevertheless performs filtering in order to determine fidelity frequency. Therefore, IOPT = 1 requires that TAPE2 contain several filter levels to be defined on this line. Furthermore, the algorithm requires that these filters be in descending order (e.g., FL0(1) = 5000., FL0(2) = 2000., FL0(3) = 1000., etc.). The values for FL0 in this series may be chosen by the analyst. However, bounding values of FL0(1) = 5000. and FL0(7) = 50. with a reasonable spread of values for FL0(I), I = 2,6 between these, have proven to be adequate. Additionally, each FL0(I) must be less than or equal to the Nyquist frequency for the digital filter to remain stable. (Note that if either FL0(1) or FL0(7), i.e., the limiting cases, is determined to be the fidelity frequency, the values should be altered accordingly and the program resubmitted.)

These four lines complete the input deck needed to submit a FOURFIT run. An example input deck is listed below. The program, will subsequently compute a 6000 point FFT on data read in the units of psi and seconds (line 1). The initial estimated pressure and yield pair are 20. MPa and 2. KT, respectively (line 2). The third line indicates that a fit will be performed. The second value in this line represents the

filter switch and, since this run asks for a fit, it will not be used. The final line of input lists the seven low pass filter levels, in Hz, to be tested for locating the low pass fidelity frequency.

Column

5	10	15	20	30	40	50	60	70
6000	1	-1						
20.	2.							
1	-1							
5000.	2000.	1000.	500.	200.	100.	50.		

### 3.2. PROGRAM STRUCTURE

#### 3.2.1. Data Calculations

IOPT equal to 2 is the simplest option to perform and, hence, the option taking the most direct calculation route. This option simply requires a subroutine to read the data, a subroutine to integrate that data for impulse and a subroutine to calculate the Fourier transform of the record. For IFILT greater than 1 (filters to be executed) the impulse and FFT are not calculated. Instead, a filter subroutine is called and the record is low pass filtered at specified cutoff frequencies.

The program FOURFIT, as listed in Appendix A, calls the subroutine EBREAD to read the data pressure histories. EBREAD is set up to read a card image format (EBCDIC) tape of the data and its header. The format of EBREAD is the format of several tapes analyzed by the author which were provided by the U.S. Army Engineer Waterways Experiment Station (WES). The format that those tapes employed was pressure data written as five data values per card (5E16.8). The set of cards for a given trace is preceded by a header record containing shot and data information (i.e., shot title, gage title, time step, total number of points) in the format of 3(2A10), E15.8, I5. These tapes have been written in psi for pressure and the program converts the

values to MPa. The time step is written in seconds. Any tape of different format must be accompanied by a substitution for EBREAD to read that data. However, this new subroutine must retain the structure of EBREAD if the program is to perform properly. This includes proper units (pressure in MPa, time in seconds), proper ordering of calls to impulse, FFT and filtering subroutines and identical writes to TAPE48.

After the data has been read, IOPT equal to 2 causes EBREAD to take one of two paths, depending on the value of IFILT. If filtering is not to be done, the subroutine causes the impulse history and the Fourier amplitude spectrum to be calculated. Subroutine IMPULSE integrates the data by Simpson's approximation. Subroutine FFTRC computes the fast Fourier transform after the algorithm of Singleton (Ref. 7). On the other hand, if filter histories are desired, subroutine FILTER filters the data using the recursive equations derived for a two pole low pass Butterworth filter as found in, for example, Reference 8.

### 3.2.2. Speicher-Brode Calculations

IOPT equal to 3 causes calculation of a Speicher-Brode pressure history and either its impulse and FFT or its specified low pass filtered pressure histories. Structure of subroutine SPBRODE is similar to that of EBREAD except that the data reads are substituted for by the Speicher-Brode equations. Also, SPBRODE requires a target range to perform its calculations. Therefore, before entering into SPBRODE, the program utilizes subroutines RANGE and PPEAK to iterate on the distance from surface burst ground zero for the given PSOI and WI pair specified. Impulse and FFT or filter histories are calculated as described for IOPT equal to 2.

### 3.2.3. Fit to Data

A value of IOPT equal to 1 causes the code to find a best fit nuclear waveform for the data. That data is read, integrated and Fourier transformed. A least squares algorithm finds a best fit to the data Fourier amplitude spectrum based on an equation, parametric in peak pressure and yield, which describes the scaled Speicher-Brode Fourier amplitude spectra. The actual best fit Speicher-Brode waveform is calculated, integrated and Fourier transformed for comparison to the data in the form of plots. The data pressure history and the equivalent Speicher-Brode are low pass filtered at several levels of frequency cutoff. The peaks of these filtered histories are compared in the determination of fidelity frequency.

The best fit search is performed within the subroutine FIT. This subroutine is modeled after a similar subroutine discussed in Reference 9. The search begins with a set of five peak pressure values and five yield values. These values are equivalent to the product of the coefficients .1, .4, 1., 4. and 10. times PSOI and WI. The final results for equivalent peak overpressure and yield are found within these values. (If the final result for either pressure or yield is either .1 or 10. times PSOI or WI, respectively, i.e., the limiting cases, the analyst is advised to alter the seeds accordingly and/or to check the quality of the data.)

Subroutine FIT takes a value of peak overpressure, PP, and pairs that value with each of the five yield values, W. The comparison between each candidate Speicher-Brode and the data occurs after, for each value of frequency for the data spectrum, a value of ideal nuclear Fourier amplitude is computed using the parametric equation below.

$$A1 = .1788PP^{-0.72}(F_s)^{-(PP)^{-0.103}} \quad (8a)$$

$$A2 = .01474PP^{-0.15}\left(\frac{F_s}{F_{so}}\right)^{-1.75} \quad (8b)$$

$$A3 = .0011PP^{(PP)^{-0.234}}\left(\frac{F_s}{F_{so}}\right)^{-2.15} \quad (8c)$$

$$A4 = .00132(F_s)^{-0.547} \quad (8d)$$

$$A5 = .01034PP^{-0.113}(F_s)^{-1}\left(\frac{F_s}{F_{so}}\right)^{-1.5} \quad (8e)$$

$$A6 = .000011PP^{0.77}\left(\frac{F_s}{F_{so}}\right)^{-7.5} \quad (8f)$$

$$A7 = .0000666PP^{0.3}\left(\frac{F_s}{F_{so}}\right)^{-1.5} \quad (8g)$$

$$ASCL = A1 - A2 + A3 + A4 + A5 - A6 + A7 \quad (8h)$$

$$A_{SB} = ASCL \times PP \times W^{1/3} \quad (8i)$$

where  $F_s$  = yield scaled frequency ( $F \times W^{1/3}$ )

$F_{so}$  = yield scaled fundamental frequency ( $F_0 \times W^{1/3}$ )

$F_0$  = 1/positive phase duration

ASCL = scaled Speicher-Brode Fourier amplitude

$$(A_{SB}/(P_{so} \times W^{1/3}))$$

$A_{SB}$  = estimated Speicher-Brode Fourier amplitude

This equation represents a fit to the normalized surface burst Speicher-Brode Fourier amplitude spectra shown in Figure 15. (Use of this equation is facilitated when, for each candidate fit, successive calls to RANGE and PPEAK calculate the positive phase duration.)

For a given data frequency, equation 3 is used to calculate a Speicher-Brode amplitude for the trial peak pressure and yield pair. In order to assimilate the graphical methodology, which is carried out in log-log form, the common logarithm of the amplitude estimate is computed. The difference between this last value and the common logarithm of the data amplitude is computed and then is squared to accomodate algebraic sign. To further assimilate the graphical method, this difference is divided by the particular data frequency. This last step considers that the FFT is computed using a constant frequency step. Therefore, the point density increases by an order of magnitude with each decade increase in frequency. Division by the frequency compensates for the weighting that results.

The value just computed is added in a summation of squared differences for the PP/W pair for the present trial. This summation process is repeated starting at the data fundamental frequency and continuing to some high frequency (a value which is a function of the data record) which sufficiently includes the significant portion of the data. (This final frequency must be chosen so as to include the peak of the data, but must be limited to avoid extensive calculation within the high point density "record noise" frequency regime.) The results of this summation provide a value DELTAW for the present pressure/yield pair.

A DELTAW value is computed for each of the other candidate yields until, for the given PP(J), five DELTAW(I) values are available for comparison. The minimum of these five values is then located and the next iteration occurs with a new set of yields replacing the old set with the yield which gave the minimum DELTAW(I) being the central value. (For

example, for  $W(I)$ ,  $I = 1,5$ ,  $\Delta W(2)$  may have been a minimum. For the next iteration, then,  $W(2)$  becomes the new  $W(3)$ ;  $W(1)$  remains unchanged and the past  $W(3)$  becomes the new  $W(5)$ . The new  $W(2)$  and  $W(4)$  values are intermediate to the new  $W(1)$  and  $W(3)$  and the new  $W(3)$  and  $W(5)$ , respectively.) This procedure is repeated until, for the given  $PP(J)$ , the field of  $W(I)$  is narrowed so that the extremes are within 1 percent of each other (i.e.,  $2 \times (W(5) - W(1))/(W(5) + W(1)) \leq .01$ ). When this tolerance is met, the minimum  $\Delta W(I)$  of the final group is set to be  $\Delta TAP(J)$  for the given value of  $PP(J)$ .

The iteration next proceeds to the second value for  $PP(J)$  coupled with each of the original five values for yield. Eventually, four more  $\Delta TAP(J)$  values are computed and the minimum of the five  $\Delta TAP(J)$  values is determined. In this manner, the field of  $PP(J)$ ,  $J = 1,5$  is narrowed to five new values and the entire process continues until the spread of  $PP(J)$  values are limited to within a tolerance as was specified for the  $W(I)$  above. When this criterion is met, the best fit Speicher-Brode is considered to be found as the pressure/yield pair for which the final minimum  $\Delta TAP(J)$  was found. (Recall, though, that if the final pressure or yield is either .1 times or 10. times the respective seed, the validity of the answer must be checked.)

Next, for this case where  $IOPT = 1$ , a Speicher-Brode pressure history is computed for the pressure/yield pair defined by  $FIT$ . This history is integrated and Fourier transformed so that final plots, provided by program  $FOURPLT$ , represent comparisons between the data and the best fit Speicher-Brode pressure history, impulse history and Fourier amplitude spectrum. Additionally, this ideal waveform is low pass

filtered. The peaks of the filtered pressure histories are determined and compared to the peaks, at their respective cutoff frequency, of the filtered data which have also been determined. Beginning with the highest frequency filter and proceeding in descending order, the level at which the filtered data peak is within 10 percent of the filtered Speicher-Brode peak is chosen as the low pass fidelity frequency. If a fidelity frequency is not found, a value of -999. is assigned to this variable. If this value appears in the output, further investigation is warranted.

The analysis discussed in the previous paragraphs creates a file, TAPE48, which contains information to be plotted. Program FOURPLT, discussed below, utilizes this file to produce plotted output of results for the three program options (IOPT). In addition, the results for IOPT equal 1, fitting of data, will be written to the output file for the analyst's record. An example of this output is shown in Figure 16. (For IOPT equal to 3, just Speicher-Brode calculations to be done, similar output is provided.) A flow chart of FOURFIT is presented in Appendix B. Appendix C provides a flow chart of subroutine FIT.

### 3.3. PROGRAM FOURPLT

Program FOURPLT is to be used in conjunction with program FOURFIT. FOURPLT exists to attach the TAPE48 made by FOURFIT, read that file, known as TAPE9 within FOURPLT, and plot the contents. The program uses the DISSPLA plotting capabilities maintained for the DNA CDC Cyber 176 computer. A separate plotting routine allows for analysis of greater sizes of data arrays and provides for quicker turn around by dividing the core requirement of the combined job. FOURPLT requires no input other than the TAPE48 file to run successfully. A listing of program FOURPLT is provided as Appendix D.

### 3.4. PROGRAMMING NOTES

Before continuing with presentation of the results from running FOURFIT and FOURPLT, a point should be noted which will assist the operator in successfully running the codes. The Speicher-Brode Fourier amplitude equations describe the total positive phase duration of the respective pressure histories. Therefore, the data to be analyzed should similarly be carried as nearly as possible through full positive phase.

Since the amount of data that can be analyzed is set within several arrays, these arrays must be large enough to contain all of the data. This includes pressure (PRESS) and time (TTIM) to be dimensioned at least as large as NEPTS; impulse (PIMP) and impulse times (TIMP) must be dimensioned at least (NEPTS/2)-1; amplitude (AMP) and frequency (FRQ) must be at least as large as (NEPTS/2)+1. In addition, the data FFT working arrays (IWKE, WKE) must be of sufficient size. (Reference 6 contains an algorithm for computing the necessary size of these two working arrays by factoring NEPTS.) The Speicher-Brode calculations use these identical arrays and the number of points assigned to these calculations is NBPTS equal to 2048. Each array must be at least large enough to accomodate this value.

## SECTION 4

### PROGRAM RESULTS

#### 4.1. SAMPLE OUTPUT

Figures 17 to 28 illustrate the possible output from FOURFIT and FOURPLT for the various options. Figures 17 to 19 result from requesting IOPT = 2 with IFILT = -1. The program reads, integrates and Fourier transforms a data record, in this case record AB-5 from event 0.35 KBAR DISC HEST. In Figure 20, the same data record is read, IOPT = 2, but is low pass filtered, IFILT = 1, at a cutoff frequency, FL0, equal to 1000. Hz. In each case, the identifying header is presented at the top of the plot.

In Figures 21 to 23, the results of computing, integrating and Fourier transforming a Speicher-Brode pressure waveform (PSOI = 39.60 MPa, WI = 0.87 KT, IOPT = 3, IFILT = -1) are presented. Figure 24 presents this same waveform (IOPT = 3) low pass filtered (IFILT = 1) at 1000. Hz (FL0) frequency cutoff. Information to the right of the plot identifies the ideal waveform plotted. Each of the types of submittals discussed in this and the preceding paragraph require on the order of 0.5 CP seconds of execution time on the Cyber 176 computer.

Finally, Figures 25 to 27 show an example of the results of a run to fit the data record (IOPT = 1) presented in Figure 17. Both the data and the computed best fit Speicher-Brode are plotted for comparison of pressure histories, impulse histories and Fourier amplitude spectra. Figure 28 compares the data and its equivalent fit both low pass filtered at the low pass fidelity frequency identified by the fit. The job requiring a fit to this record required on the order of 80 CP seconds

execution time on the Cyber 176 computer. (The required computer time will vary as the number of data points and, hence, frequency comparisons, varies.)

#### 4.2. RESULTS OF FITTING ROUTINE

Several records from the test 0.35 KBAR DISC HEST were fit using program FOURFIT. These records were chosen because they were data histories which were fairly representative of a nuclear pressure waveform. Furthermore, these records were previously analyzed using the graphical FOURFIT technique (Ref. 3) and thus provided a basis for comparison between the program results and accepted fits.

The fits calculated for several records from the DISC HEST are shown in Figures 29 to 49. (These results are in addition to those for record AB-5 shown earlier.) These figures represent the output from running FOURFIT and FOURPLT and includes both the data and the fit compared by pressure history, impulse history and Fourier amplitude spectrum for each record. Table 1 summarizes these fits and compares the results of the program ("automated") to fits found graphically ("graphical"). The authors feel that Figures 29 to 49 show favorable comparisons. (Though some of the latest automated results do not agree closely with previous graphical results--i.e., yield values for AB-4, for AB-9 and for AB-10--the plot comparisons for these records are very acceptable.)

The program was next applied in the analysis of a second event, 0.35 KBAR HEST. FOURFIT managed to determine acceptable fits to several of the records (e.g., the fit for record 51 shown in Figures 50 to 52). However, for other records of this event, the data record and its time domain fits diverge after several milliseconds. This divergence may be

Table 1. Comparison of FOURFIT results for 0.35 KBAR  
DISC HEST: graphical (ref. 3) versus automated.

Gage	Yield (KT)			P <sub>SO</sub> (MPa)			Δ%*
	Graphical	Automated	Δ%*	Graphical	Automated	Δ%*	
AB-3	1.05	1.07	+1.9	40.	41.	+2.5	
AB-4	.52	1.15	+121.	45.	37.	-18.	
AB-5	.84	.87	+3.6	40.	40.	0.	
AB-7	.80	.97	+21.	35.	35.	0.	
AB-9	.91	.66	-38.	29.	33.	+14.	
AB-10	.66	.99	+50.	45.	42.	-6.7	
AB-12	.31	.57	+84.	50.	41.	-18.	
AB-13	.80	.73	-8.8	40.	42.	+5.0	
AVE**	.74	.86	41.**	40.	39.	8.0**	
σ**	.23	.20	43.**	6.5	3.4	7.6**	
σ/AVE	.31	.23	1.04	.16	.09	.95	

\*percent of graphical

\*\* |Δ%|

traced to trends in the pressure data which are atypical of the ideal nuclear pulse. These trends, as noted for one of the records, are discussed below.

Figure 53 presents the pressure history of record 417 from 0.35 KBAR HEST. Several variations between the ideal waveform and record 417 are readily noticeable. First, in contrast to the DISC HEST records, record 417 contains one relatively high magnitude (46 MPa), but very narrow spike suggesting a low amount of power carried in the peak of the record. This spike is followed by an extended vibratory component at about 11 MPa and another at about 7 MPa suggesting that a lower, but still fairly high frequency regime may be sustaining too much power. The remainder of the waveform shows, rather than a purely exponential decay, a decay that, at times, shows a nearly linear trend, upon which is superimposed a low frequency oscillatory component. This would foretell a rise in the amplitude spectrum in the low frequency end.

The Fourier amplitude spectrum for record 417 was computed and is presented in Figure 54. This figure fulfills the expectations resulting from review of the pressure history. The spectrum falls off rapidly between the fundamental frequency and about 150 Hz. At this point, the slope changes to a lesser decay of power toward the intermediate to high frequencies. As the Nyquist frequency is approached, the spectrum falls off more rapidly. These observations seem to correspond to the low frequency oscillation, the early time/low magnitude oscillations and the narrowness of the peak, respectively.

The factors listed above indicate that the recorded trace carries a low qualitative fidelity in comparison to the Speicher-Brode. These data

trends suggest that the fits to such records may show obvious variances in comparisons to those records. Figure 55 presents the Fourier amplitude fit determined by a FOURFIT run on record 417. It is seen that the data spectrum diverges from the fit at times, with the non-nuclear trends of the data becoming obvious. The pressure history comparison, Figure 56, also illustrates regions of divergence between the data and the nuclear waveform. The fit impulse history (Fig. 57) is seen to be a mismatch to the data beyond about 10 msec. The difficulties encountered in analysis of poor fidelity records, such as 417, indicates a need for more study into the approach for analysis of such records. For example, different frequency regimes of such data may be subject to varying weighting functions to perform the fit.

Comparisons between other records from 0.35 KBAR HEST and their respective fits are shown in Figures 58 through 72. These fits are summarized in Table 2.

Table 2. Comparison of FOURFIT results for 0.35 KBAR  
HEST: graphical (ref. 3) versus automated.

Gage	Yield (KT)			P <sub>SO</sub> (MPa)			Δ%*
	Graphical	Automated	Δ%*	Graphical	Automated	Δ%*	
411	1.01	2.67	+164.	16.	14.	-12.	
417	.75	2.70	+260.	18.	14.	-22.	
418	.67	.80	+19.	15.	15.	0.	
419	.50	.74	+48.	15.	14.	-7.	
51	.50	.59	+18.	15.	16.	+7.	
54	.74	.50	-32.	14.	17.	+21.	
55	.41	1.23	+207.	20.	17.	-15.	
AVE	.65	1.32	107.**	16.	15.	12.**	
σ	.20	.96	101.**	2.1	1.2	8.**	
σ/AVE	.31	.73	.94	.13	.077	.67	

\*percent of graphical

\*\* |Δ%|

## SECTION 5

### FILTER STUDY

The previous sections discuss the development of the FOURFIT technique and a computer code written for the purpose of performing that technique numerically. Consideration of fidelity through low pass filtering suggested that more information could be culled from data records through more extended analysis. Specifically, it was hypothesized that high pass filtering and possibly band pass filtering of the data and of the nuclear waveforms could prove insightful. For example, different frequency regimes of the simulated waveform may represent a different equivalent peak pressure and/or yield for systems with sensitivity in those frequency regimes.

An extended version of FOURFIT was written to include high pass and band pass filters. As in the low pass filter, these filter types were two pole recursive digital Butterworth filters. Extensive analysis into the effects of these filters on the Speicher-Brode waveform was undertaken. A band pass filtered ideal waveform of Figure 21 is shown in Figure 73. It can be seen that the band pass filter drastically alters the form of the signal. This most likely is due not only to a removal of low frequency power, but also to phase shifting.

Although low pass filtering left the final airblast impulse virtually unaffected, it is obvious from Figure 73 that the impulse and, hence, the power of the original signal are reduced. Several attempts were made to correlate this reduction in power to various factors. Comparisons using varying high pass cutoff and low pass cutoff combinations with various  $P_{so}/W$  pairs failed to produce any promising

results. These comparisons included studies of the filtered peaks (both positive phase and negative phase peaks) and of impulse (both positive phase and total impulses).

High pass filter studies were more promising than those regarding the band pass filter. Figure 74 presents a high pass filtered waveform from Figure 21. Although the waveform is altered similar to the effect of the band pass filter, a correlation between the filtered trace and the filter was developed. Before discussing this effect, it must first be noted that recursive digital filters are a function of the data time step as well as of the cutoff frequency and the number of filter poles. It was found that the time step dependence is an important factor for a high pass filter of a waveform such as the nuclear airblast pulse (i.e., sudden rise to peak). With this in mind, several Speicher-Brode waveforms of various peak pressure and yield combinations were calculated with the same time step for each and were then filtered at various high pass cutoff levels. Figure 75 shows the effect of cutoff frequency on the scaled peak of the filtered ideal waveform. The curve applies for all yields and represents the high pass filter peak attenuation curve for data with a sampling rate of 100 kHz (the sampling rate of the 0.35 KBAR DISC HEST). The application of the attenuation curve to the data analysis is described below.

Given the time step of the data to be analyzed, a table of values for Speicher-Brode peak attenuation as a function of those cutoff frequencies listed in the input deck (TAPE5) must be developed. This array of information is then added to the code. Then, in the process of running FOURFIT, the data must be high pass filtered and the filtered

record peaks stored. Next, the code determines a best fit Speicher-Brode and a fidelity frequency. For all systems with sensitivities below this value, the equivalent fit is a valid loading function. Systems sensitive to frequencies higher than the fidelity frequency will experience a different loading function. This different function is determined by reference to the high pass attenuation table for the ratio of filter peak to  $P_{so}$  for the specific fidelity frequency just determined. Through this value, the high pass loading function is determined by the following relation:

$$\begin{aligned} & (P_{HPD})_{FF}/(\text{Stored Ratio})_{FF} = P_{soHP} \\ \text{or} \quad & (P_{HPD})_{FF}/(P_{HPB}/P_{so})_{FF} = P_{soHP} \end{aligned} \quad (9)$$

where  $P_{HPD}$  = the peak of the high pass filtered data

$P_{HPB}$  = the peak of the high pass filtered Speicher-Brode

$P_{soHP}$  = the high pass equivalent Speicher-Brode for the data record.

The subscript FF refers to the respective values at the fidelity frequency.

No yield dependence was found in this study. Therefore, the high pass equivalent waveform is assigned a yield identical to that of the low pass equivalent waveform. Figure 76 presents a plot of record AB-5 from 0.35 KBAR DISC HEST with its FOURFIT comparison. The high pass equivalent peak overpressure is identified on the plot along with the information listed previously with FOURFIT plots. Figure 77 compares the data record high pass filtered at the fidelity frequency to the high pass equivalent Speicher-Brode filtered at the same cutoff frequency. These waveforms are seen to compare quite well.

The results of high pass equivalency have not been adequately tested. In addition, more investigation into yield dependence is

warranted. For example, Reference 10 discusses a method for removing the phase shift resulting from a filter. Application of this technique may prove useful. Therefore, though the work is promising, the FOURFIT code as presented in Appendix A does not include the capabilities discussed in this section.

## SECTION 6

### CONCLUSIONS AND RECOMMENDATIONS

Ambiguity and uncertainty in performing evaluations of airblast simulation records have suggested the need for a methodology to achieve consistent and meaningful analysis of such data. Previous studies (Refs. 1, 2, 3) have shown that the FOURFIT technique meets most requirements.

Until the present, FOURFIT has been used to graphically determine a best fit ideal nuclear waveform for a simulation record based upon comparison of the data Fourier amplitude spectrum to a set of normalized Fourier amplitude spectra derived from the formulations for the ideal nuclear airblast pressure history (i.e., "New Brode" or Speicher-Brode). In addition to providing consistent estimates for equivalent nuclear yield and peak overpressure for records from a single event, the frequency analysis provides considerable insight into the frequency content of the data relative to the ideal nuclear. Furthermore, the FOURFIT methodology allows for determination of a "fidelity" frequency. This frequency indicates a cutoff whereby systems with frequency sensitivity at or below that level experience a good simulated loading defined by the equivalent nuclear fit determined for the record. Above that frequency, the simulation breaks down.

The computer code FOURFIT, and its companion plotting routine FOURPLT, provide an automated method for fitting which allows for rapid analysis of records while eliminating analyst bias. In addition, the code allows for studies of individual records and of Speicher-Brode waveforms by allowing the analyst to specify a fast Fourier transform and integrated

impulse or low pass filtering of either type of waveform. These codes were written for use on the Defense Nuclear Agency CDC Cyber 176 computer.

The results of the application of these codes for analysis of two simulation events, 0.35 KBAR DISC HEST and 0.35 KBAR HEST indicates that the code is capable of determining nuclear fits for the records of the former of these events which compare favorably to those determined previously using the graphical methodology. It must be noted, however, that the 0.35 KBAR DISC HEST data base consisted of high fidelity, Speicher-Brode-like pulses. Data from the second event, 0.35 KBAR HEST, were not of such high fidelity. These records were analyzed graphically in the study of Reference 3 and at the time were found to be difficult to fit due to their poor fidelity marked by obvious diversions from the ideal nuclear wave shape. The FOURFIT code managed to fit several of the records rather well. However, in some cases the poor data waveforms caused the fit and the data to show poor agreement at late time. Closer examination of such records may enable better fits to be defined. However, it is not possible to automate a consistent method for fitting non-typical waveforms.

Finally, a study into the usefulness of high pass and band pass filtering yielded mixed conclusions. Although no important results were recovered from the band pass filter study, some limited insight was provided through high pass filtering. The extent of this effort was limited in the study of high pass filter effects and so was not totally conclusive. However, this study indicated that a high frequency equivalent nuclear waveform may be estimated through application of high pass filters.

Several recommendations may be made in view of the preceding comments. For example, when the available data from an event proves to be of low fidelity relative to the ideal nuclear waveform, a means for determining guidelines for pursuing the fitting of such data needs to be developed. Variable weighting schemes for the squared difference values may allow the analyst to better address the different power regimes in such signals. This analysis would be performed on a case by case basis.

Next, it is recommended that the FOURFIT code be applied to define record fidelity in addition to the low pass filter definition of fidelity frequency. It is suggested that the methodology may be expanded to enable quantification of fidelity and that, with increasing interest in the development of a high fidelity HEST, a set of fidelity guidelines may be established based upon a scheme of sum of differences between the data and its best fit Fourier amplitude spectrum. Various guidelines, as a function of frequency range, may help to determine the relative fidelity of various so-called Hi-Fi HEST candidates.

The fits to the normalized Speicher-Brode Fourier amplitude spectra have only been checked between peak pressure values of 1 MPa and 200 MPa. There is increased interest in higher overpressure regimes, on the order of 600 MPa and above. It is, therefore, recommended that the ability to fit simulated overpressure pulses in that range be demonstrated and/or developed. This would require a study of the Speicher-Brode Fourier amplitude equations to determine additional parametric validity up to, say, 1000 MPa.

It is recommended that the effects of high pass filtering on ideal and simulated nuclear overpressure histories be studied further. The high pass equivalency technique discussed in this report may perhaps be extended to evaluate the influence of high pass filters on estimates of equivalent yield for the high pass fit. This might be accomplished through use of the "zero phase shift" filter as discussed in Reference 10.

Finally, it is recommended that the computer program FOURFIT be used to determine equivalent nuclear yield and peak overpressure for all future simulation events.

## LIST OF REFERENCES

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APPENDIX A  
LISTING OF PROGRAM FOURFIT

```

PROGRAM FOURFIT(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,
TAPE2,TAPE26,TAPE48)
*****  

C PROGRAM FOURFIT ESTIMATES THE PEAK OVERPRESSURE  

C AND NUCLEAR YIELD FOR AIREBLAST SIMULATION RECORDS  

C BY COMPARING FITS OF THE DATA FOURIER AMPLITUDE  

C SPECTRUM TO THE FOURIER AMPLITUDE SPECTRA OF TRIAL  

C SPEICHER-BRODES. RESULTS ARE WRITTEN TO A FILE  

C (TAPE48) TO BE READ AND PLOTTED BY PROGRAM FOURPLT.  

C WRITTEN BY D. W. STEEDMAN, APPLIED RESEARCH ASSOC.,  

C INC., ALBUQUERQUE, NM, FEB 1984.  

*****  

C  

COMMON /FFT    / FREQ(3001),AMP(3001),XFFT(3001)
COMMON /TERAT/  W(5),P(5),DELTAW(5),DELTAP(5),YLD(5)
COMMON /THIST /  TTIM(6000),PRESS(6000),TIMP(2999),PIMP(2999),
                PFILT(6000)
COMMON /IMP    / IIMP,DTD,DTB,TPEB,DTBN
COMMON /POINTS / NEPTS,NBPTS,NI,NEF,NBF
COMMON /ESTIM / PSOI,WI,PP,W13,PSOF,WF,FSO
COMMON /PEAK   / DP,TA,PSO,ALPF
COMMON /SBCONS/ RSKFT,YS,S,XM
COMMON /FILT   / IFILT,FLO(7),PFDM(7),PFEM(7)
COMMON /PLGTV / ITL(8),ISTL(8),IDE
COMMON /UNITS / IUNITS,JUNITS
COMMON /COUNT  / ICOUNT,IOPT,LFILT
COMPLEX XFFT

C TAPE2 CONTAINS INPUT PARAMETERS
NEPTS = NO. OF POINTS TO BE READ FROM TAPE
IUNITS = 1 FOR TAPE INPUT PRESSURE IN PSI
        =-1 FOR TAPE INPUT PRESSURE IN MPA
JUNITS = 1 FOR TAPE INPUT TIME IN MILLISECONDS
        =-1 FOR TAPE INPUT IN SECONDS
PSOI = INITIAL PEAK OVERPRESSURE ESTIMATE IN MPA
WI = INITIAL NUCLEAR YIELD ESTIMATE IN KT
IOPT = 1: FITTING ROUTINE TO BE DONE
        = 2: JUST FOURIER TRANSFORM THE DATA
        = 3: JUST FOURIER TRANSFORM THE SPEICHER-BRODE
        DEFINED BY PSOI, WI
IFILT = 1 FOR FILTER TO BE EXECUTED
        =-1 FOR NO FILTER
FLO = LOW PASS CUTOFF FREQUENCY IN HZ (UP TO 7 ALLOWED)
      (NOTE: FOR LESS THAN 7 FILTERS, FLO
      MUST BE SET TO 0. TO ESCAPE THE LOOP.)  

C  

REWIND 2
READ(2,111) NEPTS,IUNITS,JUNITS
READ(2,112) PSOI,WI
READ(2,113) IOPT,IFILT
READ(2,115) (FLO(I),I=1,7)
111 FORMAT(3I5)
112 FORMAT(2F5.2)
113 FORMAT(2I5)
115 FORMAT(7F10.0)
      WRITE(6,11) PSOI,WI
1  FORMAT(2X,PSOI = *,F5.2,X,*,WI = *,F5.2)
      WRITE(48,113) IOPT,IFILT
      ICOUNT = 0
      NBPTS = 2048
      IF(IOPT.EQ.3) GO TO 7
      CALL EBREAD
      IF(IOPT.EQ.2) GO TO 666
      CALL FIT
7  ICOUNT = 1
      CALL RANGE
      CALL SPBRODE
666 END

```

```

SUBROUTINE EBREAD
  ****
  THIS SUBROUTINE READS PRESSURE VALUES FROM AN
  EBCDIC TAPE BASED UPON THE FORMAT PREVIOUSLY
  USED BY WES.
  ****

COMMON /FFT/  FRO(3001),AMP(3001),XFFT(3001)
COMMON /POINTS/ NEPTS,NBPTS,NI,NEF,NEF
COMMON /THIST/ TTIM(6000),PRESS(6000),TIMP(2999),PIMP(2999),
  PFILT(6000)
COMMON /FILT/ IFILT,FLD(7),PFDMX(7),PFBMX(7)
COMMON /IMP/ IIMP,DTD,DTB,TPEB,DTBN
COMMON /UNITS/ IUNITS,JUNITS
COMMON /PLOTV/ ITL(8),ISTL(8),IDB
COMMON /COUNT/ ICOUNT,IOPT,LFILT
COMPLEX XFFT
DIMENSION IWKE(2000),WKE(2000)
DIMENSION DUM(3),DA(5)

C      DELP IS THE DATA BASELINE SHIFT. BE
C      SURE THAT IT IS IN THE PROPER UNITS.
DELP = 0.0
REWIND26

C      READ TAPE HEADER INFORMATION
C
READ(26,30) ITL(3),ITL(4),
  DUM(1),DUM(2),
  ITL(1),ITL(2),
  DTD,NP
30 FORMAT(3(2A10),E15.8,I5)
C
  ITL(5) = 10H PRESSURE
  ITL(6) = 10HHISTORY
  ITL(7) = 10H
  ITL(8) = 10H
  WRITE(48,35) (ITL(L),L=1,8)
35 FORMAT(8A10)
  DO 20 I=1,NEPTS
    TTIM(I) = 0.
    PRESS(I) = 0.
20 CONTINUE
  IF(EOF(26)) 900,901

C      SET UP DATA UNITS CONVERSIONS:
C      MSEC TO SEC AND PSI TO MPA.
901 IF(JUNITS.GE.1) DTD = DTD-.001
  PFACT = .006894757
  IF(IUNITS.LT.0) PFACT = 1.
  IP = 1
  TIME = 0.
  NLINE = NEPTS/5
  RLINE = FLOAT(NEPTS)/5.
  IF(RLINE.GT.NLINE) NLINE = NLINE+1

C      READ PRESSURE VALUES
C
  DO 40 J=1,NLINE
    READ(26,50) (DA(JJ),JJ=1,5)
50  FORMAT(5E16.8)
  IF(EOF(26)) 900,902
902 DO 60 K=1,5
  TTIM(IP) = TIME
  P = DA(K)
  PRESS(IP) = (P-PFACT)-DELP
  IP = IP+1
  TIME = TIME+DTD
60 CONTINUE
40 CONTINUE

C      SPLINE THE END OF THE DATA TO ZERO IN
C      CASE OF A TRUNCATED RECORD
  TLAST = TTIM(NEPTS)
  CALL SPLINE(TLAST,NEPTS,TTIM,PRESS)

```

```

C
C      IF IOPT = 1, FIND THE TIME TO DATA
C      PEAK TO AID IN PHASING THE OVERLAYS.
C      AID IN PHASING OVERLAYS
C      PMAX = 0.
C      DO 78 IK=1,NEPTS
C          PMAX = AMAX1(PMAX,PRESS(IK))
C          IF(PMAX.EQ.PRESS(IK)) TPEB = TTIM(IK)
C 78 CONTINUE
C
C      REMOVE BASELINE CORRECTION FOR POINTS
C      BEFORE THE ARRIVAL OF THE SHOCK
C      DO 77 M=1,NEPTS
C          IF(TTIM(M).GT.TPEB) GO TO 990
C          PRESS(M) = PRESS(M)+DELF
C 77 CONTINUE
C
C      GO TO 990
C 900 WRITE(6,70)
C      70 FORMAT(10A,*END-OF-FILE REACHED EARLY*///)
C 990 CONTINUE
C      IF(IOPT.NE.2) GO TO 45
C      CALL FMAX(PRESS,NEPTS,YPMN,YPMX)
C      CALL FMAX(TTIM,NEPTS,XPMN,XPMX)
C      WRITE(48,100) NEPTS,XPMN,XPMX,YPMN,YPMX
C      IF(IFILT.LT.0) GO TO 700
C
C      CALL FOR FILTERS TO BE EXECUTED
C      CALL FLOOR(TTIM,PRESS,DTD,NEPTS,PFILT)
C      RETURN
C
C 700 WRITE(48,105) (TTIM(K),K=1,NEPTS)
C      WRITE(48,105) (PRESS(KL),KL=1,NEPTS)
C 100 FORMAT(15.4E15.8)
C 105 FORMAT(10E15.8)
C      45 IIMP = 1
C
C      IMPULSE
C
C      CALL IMPULSE(IIMP,DTD,NEPTS,NI)
C      IF(IDPT.NE.2) GO TO 110
C      ITL(5) = 10H IMPULSE H
C      ITL(6) = 10HISTORY
C      WRITE(48,115) ITL(5),ITL(6)
C      CALL FMAX(TIMP,NI,XIMN,XIMY)
C      CALL FMAX(PIMP,NI,YIMN,YIMX)
C      WRITE(48,100) NI,XIMN,XIMX,YIMN,YIMX
C      WRITE(48,105) (TIMP(IH),IH=1,NI)
C      WRITE(48,105) (PIMP(JH),JH=1,NI)
C 115 FORMAT(2A10)
C
C      FIND THE FOURIER TRANSFORM AND CALCULATE AMPLITUDE.
C
C 110 TTOT = DTD*NEPTS
C      FREQUENCY INCREMENT
C      DFE = 1./TTOT
C      FOE = 0.
C
C      FOURIER TRANSFORM
C      CALL FFTRC(PRESS,NEPTS,XFFT,IWKE,WKE)
C      XRE = REAL(XFFT(1))/(2*NEPTS)
C      XIE = AIMAG(XFFT(1))/(2*NEPTS)
C      FOE = FOE+DFE
C
C      AMPLITUDE SPECTRUM
C      FRO(1) = FOE
C      AMP(1) = SORT(2.-(XRE+XRE+XIE+XIE))*TTOT
C      NEF = NEPTS/2+1
C      DO 80 JK=2,NEF
C          FOE = FOE+DFE
C          FRO(JK) = FOE
C          XRE = REAL(XFFT(JK))/NEPTS
C          XIE = AIMAG(YFFT(JK))/NEPTS
C          AMP(JK) = SORT(XRE+XRE+XIE+XIE)*TTOT
C 80 CONTINUE
C

```

```

IF(IDPT.NE.2) RETURN
ITL(5) = 10H FOURIER A
ITL(6) = 10HAMPLITUDE S
ITL(7) = 10HPECTRUM
CALL FMAX(FRQ,NEF,XFMN,XFMX)
CALL FMAX(AMP,NEF,YFMN,YFMX)
WRITE(48,117) ITL(5),ITL(6),ITL(7)
117 FORMAT(3A10)
WRITE(48,100) NEF,XFMN,XFMX,YFMN,YFMX
WRITE(48,105) (FRQ(LI),LI=1,NEF)
WRITE(48,105) (AMP(JI),JI=1,NEF)
RETURN
END
SUBROUTINE FIT
*****
C THIS SUBROUTINE ITERATES ON YIELD WITHIN ITERATIONS ON
C PEAK PRESSURE. ITS AIM IS TO REDUCE THE SUM OF THE SQUARES
C OF THE DIFFERENCE BETWEEN THE DATA AMPLITUDE AT F(I) AND
C THE ESTIMATED SPEICHER-BRODE AMPLITUDE AT F(I) DIVIDED
C BY F(I) BASED UPON A TOLERANCE ON PEAK PRESSURE AND YIELD.
C END RESULT IS A FINAL ESTIMATE OF PEAK OVERPRESSURE
C (PSOF) AND YIELD (WF). ALSO, AN ESTIMATE OF THE GOODNESS
C OF FIT (DELL) IS DETERMINED. PRESSURE IS IN MPa, YIELD IS
C IN KT.
*****
C
COMMON /POINTS/ NEPTS,NBPTS,NI,NEF,NBF
COMMON /ESTIM / PSOI,WI,PP,W13,PSOF,WF,FSO
COMMON /ITERAT/ W(5),P(5),DELTAW(5),DELTAP(5),YLD(5)
COMMON /FFT   / FRQ(3001),AMP(3001),XFFT(3001)
COMMON /PEAK  / DP,TA,PSO,ALPF
DATA TOL/.01/
C
P(1) = .1*PSOI
P(2) = .4*PSOI
P(3) = 1.0*PSOI
P(4) = 4.*PSOI
P(5) = 10.*PSOI
JPRESS = 0
C
C LOOP ON PRESSURE TOLERANCE
C
DO 100 JJ=1,50
  JPRESS = JPRESS+1
  JMIN = 2
  JMAX = 4
  IF(JPRESS.NE.1) GO TO 105
  JMIN = 1
  JMAX = 5
C
C LOOP ON PRESSURE
C
105 DO 200 II=JMIN,JMAX
  PP = P(II)
  JYLD = 0
  W(1) = 0.1*WI
  W(2) = 0.4*WI
  W(3) = 1.0*WI
  W(4) = 4.0*WI
  W(5) = 10.*WI
C
C LOOP ON YIELD TOLERNACE
C
DO 250 KK=1,50
  JYLD = JYLD+1
  IMIN = 2
  IMAX = 4
  IF(JYLD.NE.1) GO TO 255
  IMIN = 1
  IMAX = 5
C
C LOOP ON YIELD
C
255 DO 300 LL=IMIN,IMAX
  W13 = W(LL)*.33333
  IF(LL.NE.1) GO TO 256
  CALL RANGE

```

```

C
C      DETERMINATION OF RESIDUALS
C
256 DELTAW(LL) = 0.
DO 350 LK=1,NEF
  FSCL = FRQ(LK)*W13
  IF(FRQ(LK).GT.7000.) GO TO 300
  IF(FSCL.LT.FSO) GO TO 350
  CALL AMPALG(FSCL,BAMP)
  AMPN = ALDG10(AMP(LK))
  BAMPN = ALDG10(BAMP)
  DF2 = FRQ(LK)*FRQ(LK)
  DELTAA = (AMPN-BAMPN)/FRQ(LK)
  IF(FRQ(LK).LT.1000.) DELTAA = 2.*DELTAA
  IF(FRQ(LK).GT.5000. .AND. FRQ(LK).LT.7000.)
  *      DELTAA = 2.*DELTAA
  DELTAA = DELTAA*DELTAA
  DELTAW(LL) = DELTAW(LL)+DELTAA
350 CONTINUE
300 CONTINUE
C
C      RESET YIELDS
C
EPSW = ABS(W(5)-W(1))*2./(W(5)+W(1))
IF(EPSW.LT.TOL) GO TO 360
CALL RESETW
250 CONTINUE
WRITE(6,1250)
1250 FORMAT(2X,•FAILED TO CONVERGE ON YIELD•)
STOP 14
360 CONTINUE
DWMIN = AMIN1(DELTAW(1),DELTAW(2),DELTAW(3),DELTAW(4),DELTAW(5))
DO 365 MM=1,5
  IF(DELTAW(MM).EQ.DWMIN) KW = MM
365 CONTINUE
YLD(II) = W(KW)
DELTAP(II) = DELTAW(KW)
200 CONTINUE
C
C      RESET PRESSURES
C
EPSP = ABS(P(5)-P(1))*2./(P(5)+P(1))
IF(EPSP.LT.TOL) GO TO 400
CALL RESETP
100 CONTINUE
WRITE(6,1100)
1100 FORMAT(2X,•FAILED TO CONVERGE ON PEAK PRESSURE•)
STOP 10
400 DPMIN = AMIN1(DELTAP(1),DELTAP(2),DELTAP(3),DELTAP(4),DELTAP(5))
DO 405 NN=1,5
  IF(DELTAP(NN).EQ.DPMIN) KP = NN
405 CONTINUE
W13 = YLD(KP)**.33333
PP = P(KP)
DELL = DELTAP(KP)/NEF
RETURN
END
SUBROUTINE AMPALG(FSCL,BAMP)
*****
C THIS SUBROUTINE ESTIMATES THE FOURIER AMPLITUDE OF THE TRIAL
C PEAK PRESSURE AND YIELD BASED UPON A FIT TO THE SUITE OF
C OF NORMALIZED SPEICHER-BRODE FOURIER AMPLITUDE SPECTRA.
C THE ALGORITHM USES SCALED FREQUENCY OF INTEREST (FSCL),
C SCALED FUNDAMENTAL FREQUENCY OF THE S-B OF CONCERN (FSO)
C AND THE PEAK OVERPRESSURE (PP) TO CALCULATE THE SCALED
C AMPLITUDE. THE ALGORITHM USES PRESSURE IN MPa AND YIELD
C IN KT. THE EQUATIONS ARE FOR A SURFACE BURST ONLY. THEY ARE
C VALID FOR ANY YIELD AND FOR PEAK OVERPRESSURE UP TO 100MPa
*****
C
C      COMMON /ESTIM/ PSD1,W1,PP,W13,PSDF,WF,FSO
C
A1 = .1788*PP**(-.72)*(FSCL**(-1.+PP**(-.103)))
A2 = .01474*PP**(-.15)*(FSCL/FSO)**(-1.75)
A3 = .0011*PP**(-.234)*(FSCL/FSO)**(-2.15)
A4 = .00132*FSCL**(-.547)
A5 = .01034*PP**(-.113)*(1./FSCL)*(FSCL/FSO)**(-1.5)
A6 = .000011*PP**(.77)*(FSCL/FSO)**(-7.5)
A7 = .0000666*PP**(.3)*(FSCL/FSO)**(-1.5)
ASCL = A1-A2+A3+A4+A5-A6+A7
BAMP = ASCL*PP=W13
RETURN
END

```

```

SUBROUTINE RESETW
C
C      THIS SUBROUTINE RESETS THE FIVE YIELD VALUES BASED
C      UPON THIS ITERATION'S MINIMUM RESIDUAL.
C
C
C      COMMON /ITERAT/ W(5),P(5),DELTAW(5),DELTAP(5),YLD(5)
C
C      FIND THE MINIMUM DELTA
IF(DELTAW(5).LT.DELTAW(4)) GO TO 10
IF(DELTAW(4).LT.DELTAW(3)) GO TO 20
IF(DELTAW(3).LT.DELTAW(2)) GO TO 30
IF(DELTAW(2).LT.DELTAW(1)) GO TO 40
C
C      REDEFINE YIELDS BASED UPON THE MINIMUM
C
C      IF DELTAW(1) IS MIN.
DYLD = (W(2)-W(1))*0.25
W(5) = W(2)
DELTAW(5) = DELTAW(2)
GO TO 50
C
C      IF DELTAW(5) IS THE MINIMUM.
10 DYLD = (W(5)-W(4))*0.25
W(1) = W(4)
DELTAW(1) = DELTAW(5)
GO TO 50
C
C      IF DELTAW(4) IS THE MINIMUM.
20 DYLD = (W(5)-W(3))*0.25
W(1) = W(3)
DELTAW(1) = DELTAW(4)
GO TO 50
C
C      IF DELTAW(3) IS THE MINIMUM.
30 DYLD = (W(4)-W(2))*0.25
W(1) = W(2)
W(5) = W(4)
DELTAW(1) = DELTAW(2)
DELTAW(5) = DELTAW(3)
GO TO 50
C
C      IF DELTAW(2) IS THE MINIMUM.
40 DYLD = (W(3)-W(1))*0.25
W(5) = W(3)
DELTAW(5) = DELTAW(2)
50 W(2) = W(1)+DYLD
W(3) = W(2)+DYLD
W(4) = W(3)+DYLD
RETURN
END
SUBROUTINE RESETP
C
C      THIS SUBROUTINE RESETS THE FIVE PRESSURE VALUES
C      BASED UPON THIS ITERATION'S MINIMUM RESIDUAL.
C
C
C      COMMON /ITERAT/ W(5),P(5),DELTAW(5),DELTAP(5),YLD(5)
C
C      FIND THE MINIMUM DELTAP
IF(DELTAP(5).LT.DELTAP(4)) GO TO 10
IF(DELTAP(4).LT.DELTAP(3)) GO TO 20
IF(DELTAP(3).LT.DELTAP(2)) GO TO 30
IF(DELTAP(2).LT.DELTAP(1)) GO TO 40
C
C      REDEFINE PRESSURES BASED UPON THE MINIMUM
C
C      IF DELTAP(1) IS THE MINIMUM.
DPRESS = (P(2)-P(1))*0.25
P(5) = P(2)
W(5) = W(2)
DELTAP(5) = DELTAP(2)
GO TO 50

```

```

C
C      IF DELTAP(5) IS THE MINIMUM.
10 DPRESS = (P(5)-P(4))*0.25
P(1) = P(4)
W(1) = W(4)
DELTAP(1) = DELTAP(4)
GO TO 50
C
C      IF DELTAP(4) IS THE MINIMUM.
20 DPRESS = (P(5)-P(3))*0.25
P(1) = P(3)
W(1) = W(3)
DELTAP(1) = DELTAP(3)
GO TO 50
C
C      IF DELTAP(3) IS THE MINIMUM.
30 DPRESS = (P(4)-P(2))*0.25
P(1) = P(2)
W(1) = W(2)
DELTAP(1) = DELTAP(2)
P(5) = P(4)
W(5) = W(4)
DELTAP(5) = DELTAP(4)
GO TO 50
C
C      IF DELTAP(2) IS THE MINIMUM.
40 DPRESS = (P(3)-P(1))*0.25
P(5) = P(3)
W(5) = W(3)
DELTAP(5) = DELTAP(3)
50 P(2) = P(1)+DPRESS
P(3) = P(2)+DPRESS
P(4) = P(3)+DPRESS
RETURN
END
SUBROUTINE RANGE
*****
THIS SUBROUTINE IS AN ITERATION TO FIND THE RANGE
OF THE ESTIMATED PEAK PRESSURE FOR THE ESTIMATED
YIELD. THIS IS NECESSARY FOR COMPUTATION OF THE
SPEICHER-BRODE PRESSURE HISTORY, TIME OF ARRIVAL
AND POSITIVE PHASE DURATION.
*****
C
COMMON /ESTIM / PSDI,WI,PP,W13,PSOF,WF,FSO
COMMON /PEAK / DP,TA,PSO,ALPF
COMMON /SBCONS/ RSKFT,YS,S,XM
COMMON /COUNT / ICOUNT,IOPT,LFILT
C
INITIAL RANGE SPREAD
IF(IOPT.NE.3) GO TO 78
PP = PSOI
W13 = WI**.33333
78 R1 = 0.01
R2 = 0.1
R3 = 1.0
R4 = 10.
C
HDB EQUAL TO ZERO
Y = 0.
YS1 = 0.
YS2 = 0.
YS3 = 0.
YS4 = 0.
DO 100 I=1,1000
RS1 = R1/W13
RS2 = R2/W13
RS3 = R3/W13
RS4 = R4/W13
C
CALCULATE PSO FOR EACH TRIAL SCALED RANGE
CALL PPEAK(RS1,YS1,P1)

```



```

C SUBROUTINE PREAK(X,Y,PEAKP)
C ***** THIS SUBROUTINE CALCULATES THE PEAK OVERPRESSURE (MPA),
C ***** TIME OF ARRIVAL (TA,MS/KT**1/2), AND POSITIVE PHASE
C ***** DURATION (DP,MS/KT**1/3) AFTER SPEICHER-BRODE, JUNE, 1982.
C *****

C COMMON /PEAK / DP,TA,PSO,ALPF
C COMMON /SBCONS/ RSKFT,YS,S,XM

C XLEAST = 1.E-9
C YLEAST = 1.E-9
C ZMAX = 100.
C IF(X.LT.XLEAST) X = XLEAST
C IF(Y.LT.YLEAST) Y = YLEAST
C R = SQRT(X*X+Y*Y)
C R2 = R*R
C R3 = R*R2
C R4 = R2+R2
C R6 = R2+R4
C R8 = R4+R4
C Z = Y/X
C Z2 = Z*Z
C Z3 = Z-Z2
C Z5 = Z2-Z3
C Z17 = Z**17.
C Z18 = Z**18.
C Y7 = Y**7.
C IF(Z.GT.ZMAX) Z = ZMAX
C XM = 170.*Y/(1.+337.*Y**.25)+.914*Y**2.5

C SCALED TIME OF ARRIVAL
C
C U1 = (.543-21.8*R+386.*R2+2383.*R3)*R8
C U2 = 2.99E-14-1.91E-10*R2+1.032E-6*R4-4.43E-6*R6
C U3 = (1.028+2.087*R+2.69*R2)*R8
C UTA = U1/(U2+U3)
C TA = UTA
C IF(X.LT.XM) GO TO 101
C W1 = (1.086-34.605*R+486.3*R2+2383.*R3)*R8
C W2 = 3.0137E-13-1.2128E-9*R2+4.128E-6*R4-1.116E-5*R6
C W3 = (1.632+2.629*R+2.69*R2)*R8
C WTA = W1/(W2+W3)
C TA = UTA*XM/X+WTA*(1.-XM/X)

C SCALED POSITIVE PHASE DURATION
C
C 101 S = 1.-1.1E10*Y7/(1.+1.1E10*Y7)-(2.441E-8*Y*Y/
C * (1.+9.E10*Y7))/(1./(4.41E-11*X**10.))
C DP = ((1640700.+24629.*TA+416.15*TA*TA)/
C * (1080.+619.76*TA+TA*TA))
C * (.4+.001204*(TA**1.5)/(1.+.001559*TA**1.5)+/
C * (.0426+.5486*(TA**.25)/(1.+.00357*TA**1.5))*S)

C AA = 1.22-(3.908*Z2)/(1.+810.2*Z5)
C BB = 2.321+(Z18/(1.+1.113*Z18))*6.195-(.03831*Z17)/
C * (1.+.02415*Z17)+.6692/(1.+4164.*Z**8.)
C CC = 4.153-(1.149*Z18)/(1.+1.641*Z18)-1.1/(1.+2.771*Z**2.5)
C DD = -4.166+(25.76*Z**1.75)/(1.+1.382*Z18)+6.257*Z/(1.+3.219*Z)
C EE = 1.-(.004642*Z18)/(1.+.0038E6*Z18)
C FF = .6096+(2.879*Z**9.25)/(1.+2.359*Z**14.5)-17.15*Z2/
C * (1.+71.66*Z3)
C GG = 1.83+5.361*Z2/(1.+.3139*Z**6.)
C HH = -(64.67*Z5+.2905)/(1.+441.5*Z5)-1.389*Z/(1.+49.03*Z5)+/
C * (.808*Z**1.5)/(1.+154.5*Z**3.5)+(.0014*R2/(1.-.158*R+/
C * .0486*R**1.5+.00128*R2))-(1./(1.+2.*Y))

C PEAK OVERPRESSURE
C PO = 10.47/(R**AA)+BB/(R**CC)+DD*EE/(1.+FF*R**GG)+HH
C PEAKP = PO+.006894757
C RETURN
C END

```

```

SUBROUTINE SPBRODE
C
C THIS SUBROUTINE CALCULATES THE PRESSURE HISTORY FOR
C THE FINAL PRESSURE-YIELD PAIR DETERMINED BY SUBROUTINE
C FIT. IT USES THE SPEICHER-BRODE JUNE, 1982 ALGORITHM.
C
C
COMMON /THIST / TTIM(6000),PRESS(6000),TIMP(2999),PIMP(2999),
COMMON /PFILT / PFILT(6000)
COMMON /FFT / FRO(3001),AMP(3001),XFFT(3001)
COMMON /ESTIM / PSDI,WI,PP,W13,PSUF,WF,FSO
COMMON /PEAK / DP,TA,PSD,ALPF
COMMON /FILT / IFILT,FLD(7),PFDMX(7),PFBMX(7)
COMMON /SBCONS / RSKFT,YS,S,XM
COMMON /POINTS / NEPTS,NBPTS,NI,NEF,NBF
COMMON /IMP / IIMP,DTD,DB,TPEB,DBN
COMMON /COUNT / ICOUNT,IOPT,LFILT
COMMON /PLOTV / ITL(8),ISTL(8),IDB
COMPLEX XFFT
DIMENSION IWKB(11)
DATA JCOUNT/0/
C
IF(IOPT.NE.3) GO TO 5
ITL(1) = 10H CALCULATED
ITL(2) = 10H SPEICHER-
ITL(3) = 10H BRODE PRES
ITL(4) = 10H SURE HISTO
ITL(5) = 10HRY
ITL(6) = 10H
ITL(7) = 10H
ITL(8) = 10H
WRITE(48,26) (ITL(IO),IO=1,8)
26 FORMAT(BA10)
C
C CALCULATE SPEICHER-BRODE Timestep BASED
C UPON THE POSITIVE PHASE DURATION.
DTB = DP/NBPTS
GO TO 15
5 ISTL(1) = 10H WITH FOUR
ISTL(2) = 10H IT SPEICHE
ISTL(3) = 10H R-BRODE
ISTL(4) = 10H
ISTL(5) = 10H
ISTL(6) = 10H
ISTL(7) = 10H
ISTL(8) = 10H
WRITE(48,26) (ISTL(IG),IG=1,8)
CALL FMAX(PRESS,NEPTS,YPMN,YPMX)
CALL FMAX(TTIM,NEPTS,XPMN,XPMX)
WRITE(48,200) NEPTS,XPMN,XPMX,YPMN,YPMX
WRITE(48,210) (TTIM(IU),IU=1,NEPTS)
WRITE(48,210) (PRESS(IP),IP=1,NEPTS)
200 FORMAT(15,4E15.8)
210 FORMAT(10E15.8)
ICOUNT = 0
C
C FIND THE PEAKS OF THE LOW PASS
C FILTERED DATA PRESSURE HISTORIES
DO 7 I=1,7
    CALL FILTER(DTD,NEPTS)
    CALL FMAX(PFILT,NEPTS,PFDMN,PFDMX(I))
7 CONTINUE
ICOUNT = 1
C
C CALCULATE SPEICHER-BRODE TIME STEP BASED
C UPON THE DATA TIME STEP FOR FILTERING
DTB = DTD*1000./W13
C
C CALCULATE THE SPEICHER-BRODE TIME STEP BASED
C UPON THE POSITIVE PHASE DURATION FOR OVERLAYS
35 IF(JCOUNT.EQ.1) DTB = DP/NBPTS
15 DO 25 KJ=1,NBPTS
    TTIM(KJ) = 0.
    PRESS(KJ) = 0.
25 CONTINUE

```

```

X = RSKFT
TF = TA+DP
PO = PSOF=145.038
F = (.01477*(TA**.75)/(1.+.005836*TA)+7.402E-5*(TA**2.5)/
* (1.+1.429E-8*TA**4.75)-.216)*S+.7076-3.077E-5*
* TA*TA*TA/(1.+4.367E-5*TA*TA*TA)
G = 10.+(77.58-64.99*(TA**.125))/(1.+.04348*SQRT(TA)))*S
H = 2.753+.05601*TA/(1.+1.473E-9*TA**5.)*(.01769*TA/
* (1.+3.207E-10*TA**4.25)-.03209*(TA**1.25)/(1.+9.914E-8*
* TA**4.))-1.6)*S

C          CALCULATE PRESSURE HISTORY

C          DO 400 J=1,NBPTS
C          T = TA+(J-2)*DTB
C          SAVE UNSCALED TIMES
C          TTIM(J) = T*W13/1000.
C          PRESS(J) = 0.
C          IF(T.LT.TA) GO TO 400
C          IF(T.GT.TF) GO TO 410
C          B = (F*(TA/T)**G+(1.-F)*(TA/T)**H)*(1.-(T-TA)/DP)
C          POFT = PO-E
C          IF(Y.LT.XM) DR = Y.GT.0.38) GO TO 390
C          XE = 3.039*Y/(1.+6.7*Y)
C          E = AES((Y-XM)/(XE-XM))
C          IF(E.GT.50.) E = 50.
C          D = .23+583000.-(26667.+1.E6*Y*Y)+.27*E+(.5-583000.-Y*Y/
* (26667.+1.E6*Y*Y))*E**5.
C          A = (T-1.)*(1.-(E-20.)/(1.+(E-20.)))
C          DT = 474.2*Y*(Y-XM)**1.25
C          IF(DT.LT.1.E-9) DT = 1.E-9
C          GA = (T-TA)/DT
C          IF(GA.GT.400.) GA = 400.
C          V = 1.+(3.28E11*(Y**6.)/(1.+1.5E12*Y**6.75))*(GA=GA=GA/
* (6.13+GA*GA*GA))=1./(1.+9.23*E*E))
C          C = ((1.04-240.9*(Y**4)/(1.+231.7*X**4))*(GA**7)/
* ((1.+.923*GA**8.5)*(1.+A)))*(1.-(T-TA)/DP)**B.+
* 2.3E13*Y**9./(1.+2.3E13*Y**9)
C          POFT = PO*(1.+A)*(B*V+C)
C          390 PRESS(J) = POFT/145.
C          400 CONTINUE
C
C          410 JCOUNT = JCOUNT+1
C
C          UNSCALE THE SPEICHER-BRODE TIMESTEP
C          DTBN = DTB*W13/1000.
C          IF(JCOUNT.GT.1 .OR. IOPT.EQ.3) GO TO 900
C
C          FIND THE PEAKS OF THE LOW PASS FILTERED
C          SPEICHER-BRODE PRESSURE HISTORIES
C          LFILT = 0
C          DO 17 J=1,7
C              CALL FILTER(DTBN,NFPTS)
C              CALL FMAX(PFILT,NBPTS,PFBMN,PFBM)(J)
C
C          17 CONTINUE
C
C          FIND THE LOW PASS FIDELITY FREQUENCY
C
C          DO 27 K=1,7
C              PFMAX = PFDMX(K)=0.90
C              IF(PFMAX.LE.PFBMX(K)) GO TO 47
C
C          27 CONTINUE
C          WRITE(6,37)
C          37 FORMAT(2X,*** FAILED TO LOCATE LOW PASS FIDELITY ***)
C          ALPF = -999.
C          WRITE(48,57) ALPF
C          GO TO 35
C
C          47 ALPF = FLO(K)
C          WRITE(48,57) ALPF
C
C          57 FORMAT(F10.0)
C          WRITE(6,67) ALPF
C
C          67 FORMAT(2X,*** LOW PASS FIDELITY (HZ) = .,F10.0,***)
C          IF(JCOUNT.EQ.1) GO TO 35

```

```

C      DETERMINE NUMBER OF SPEICHER-BRODE PAIRS TO
C      BE PLOTTED FOR OVERLAY
900  TE = NEPTS*DTD
      NPPTS = JFIX(TE/DTBN)
      IF(IOPT.EQ.3) NPPTS = NBPTS
      WRITE(48,450) NPPTS
450  FORMAT(I5)
      IF(IOPT.EQ.3) GO TO 810
C      AFFECT A TIME SHIFT IN SPEICHER-BRODE HISTORY
C      TO ALLOW THE OVERLAY TO BE PROPERLY PHASED
      TSHFT = (TA-W13/1000.)-TPEB
      DO 800 JT=1,NBPTS
          TTIM(JT) = TTIM(JT)-TSHFT
800  CONTINUE
C      GO TO 130
810  CALL FMAX(TTIM,NBPTS,XPMN,XPMX)
      CALL FMAX(PRESS,NBPTS,YPMN,YPMX)
      WRITE(48,840) XPMN,XPMX,YPMN,YPMX
840  FORMAT(4E15.8)
      IF(IFILT.LT.0) GO TO 130
C      CALL FOR FILTERS TO BE EXECUTED
      CALL FLOOP(TTIM,PRESS,DTBN,NBPTS,PFILT)
      RETURN
130  WRITE(48,210) (TTIM(IJ),IJ=1,NPPTS)
      WRITE(48,210) (PRESS(JI),JI=1,NPPTS)
      IF(IOPT.EQ.3) GO TO 850
C      IMPULSE
C
135  ITL(5) = 10H IMPULSE H
      ITL(6) = 10HISTORY
      WRITE(48,215) ITL(5),ITL(6)
215  FORMAT(2A10)
      CALL FMAX(TIMP,NI,XIMN,XIMX)
      CALL FMAX(PIMP,NI,YIMN,YIMX)
      WRITE(48,200) NI,XIMN,XIMX,YIMN,YIMX
      WRITE(48,210) (TIMP(IY),IY=1,NI)
      WRITE(48,210) (PIMP(IT),IT=1,NI)
850  IIMP = 2
      CALL IMPULSE(IIMP,DTBN,NPPTS,NI)
      WRITE(48,450) NI
      IF (IOPT.NE.3) GO TO 150
      ITL(3) = 10HBRODE IMPU
      ITL(4) = 10HLSE HISTOR
      ITL(5) = 10HY
      WRITE(48,225) ITL(3),ITL(4),ITL(5)
225  FORMAT(3A10)
      CALL FMAX(TIMP,NI,XIMN,XIMX)
      CALL FMAX(PIMP,NI,YIMN,YIMX)
      WRITE(48,840) XIMN,XIMX,YIMN,YIMX
150  WRITE(48,210) (TIMP(KJ),KJ=1,NI)
      WRITE(48,210) (PIMP(KL),KL=1,NI)
      IF(IOPT.NE.1) GO TO 175
C      FIND THE FOURIER TRANSFORM AND CALCULATE AMPLITUDE.
C
      ITL(5) = 10H FOURIER A
      ITL(6) = 10HAMPLITUDE S
      ITL(7) = 10HPECTRUM
      WRITE(48,225) ITL(5),ITL(6),ITL(7)
      CALL FMAX(FRQ,NEF,XFMN,XFMX)
      CALL FMAX(AMP,NEF,YFMN,YFMX)
      WRITE(48,200) NEF,XFMN,XFMX,YFMN,YFMX
      WRITE(48,210) (FRQ(I0),I0=1,NEF)
      WRITE(48,210) (AMP(IP),IP=1,NEF)
175  TOTT = DTBN-NBPTS
C      FREQUENCY INCREMENT
      DFB = 1./TOTT
      FOB = 0.
      WKB = 0
      NBF = NBPTS/2+1

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```

      DO 349 LK=1,NBF
      FRO(LK) = 0.
      AMP(LK) = 0.
      XFFT(LK) = 0.
349 CONTINUE
      CALL FFTRC(PRESS,NBPTS,XFFT,IWKB,WKB)
C      AMPLITUDE SPECTRUM
      DO 500 KK=1,NBF
      FOB = FOB+DFB
      FRO(KK) = FOB
      XRB = REAL(XFFT(KK))/NBPTS
      XIB = AIMAG(XFFT(KK))/NBPTS
      AMP(KK) = SQRT(XRB*XRB+XIB*XIB)+TOTT
500 CONTINUE
C      WRITE(48,450) NBF
      IF(IOPT.NE.3) GO TO 165
      ITL(3) = 10HBRODE FOUR
      ITL(4) = 10HIER AMPLIT
      ITL(5) = 10HUE SPECTR
      ITL(6) = 10HUM
      WRITE(48,235) ITL(3),ITL(4),ITL(5),ITL(6)
235 FORMAT(4A10)
      CALL FMAX(FRO,NBF,XFMN,XFMX)
      CALL FMAX(AMP,NBF,YFMN,YFMX)
      WRITE(48,840) XFMN,XFMX,YFMN,YFMX
165 WRITE(48,210) (FRQ(IU),IU=1,NBF)
      WRITE(48,210) (AMP(IE),IE=1,NBF)
      RETURN
      END
      SUBROUTINE FLOOP(TTIM,PRESS,DT,NF,PFILT)
C      ****
C      THIS SUBROUTINE PERFORMS THE LOOPING REQUIRED
C      TO FILTER THE DATA OR THE BRODE UP TO SEVEN
C      TIMES. FOR LESS THAN SEVEN FILTER LEVELS,
C      FLO MUST BE SET TO 0. IN THE INPUT DECK IN
C      ORDER TO ESCAPE THE LDDP.
C      ****
C
C      COMMON /FILT/ IFILT,FLD(7),PFDMX(7),PFBMX(7)
      DIMENSION TTIM(1),PRESS(1),PFILT(1)
C      DO 750 JF=1,7
      IF(FLO(JF).EQ.0.) GO TO 555
      IFLAG = 1
      WRITE(48,95) IFLAG
95      FORMAT(1S)
      WRITE(48,96) FLO(JF)
96      FORMAT(F10.0)
      DO 725 KF=1,NP
      PFILT(KF) = 0.
725      CONTINUE
C      CALL TO FILTER
      CALL FILTER(DT,NP)
      CALL FMAX(PFILT,NP,YFMN,YFMX)
      WRITE(48,100) YFMN,YFMX
100     FORMAT(2E15.8)
      WRITE(48,105) (TTIM(LF),LF=1,NP)
      WRITE(48,105) (PFILT(MF),MF=1,NP)
105     FORMAT(10E15.8)
750      CONTINUE
555      IFLAG = -1
      WRITE(48,95) IFLAG
      RETURN
      END

```

```

C SUBROUTINE SPLINE(TLAST,NP,TTIM,PRESS)
C ****
C THIS SUBROUTINE SETS UP A COSINE SQUARED SPLINE
C FUNCTION AND APPLIES IT TO THE FINAL 15% OF THE
C PRESSURE HISTORY TO AVOID A FREQUENCY IMPULSE
C IN TRUNCATED RECORDS.
C ****
C
C DIMENSION TTIM(1),PRESS(1)
C
C PIE = 3.1415927
C K = IFIX(.85*NP)
C N = NP-K+1
C T1 = TTIM(K)
C DO 10 J=1,N
C     TFACT = (TTIM(K)-T1)/(TLAST-T1)
C     SFACT = COS(TFACT*PIE*.5)
C     SFACT = SFACT*SFACT
C     PRESS(K) = PRESS(K)*SFACT
C     K = K+1
C 10 CONTINUE
C RETURN
C END
C
C SUBROUTINE IMPULSE(IIMP,DT,NP,NI)
C ****
C THIS SUBROUTINE CALCULATES THE IMPULSE OF THE INPUT
C PRESSURE DATA (IIMP = 1) OR OF THE CALCULATED SPEICHER-
C BRODE (IIMP = 2) BY SIMPSON'S APPROXIMATION.
C ****
C
C COMMON /THIST/ TTIM(6000),PRESS(6000),TIMP(2999),PIMP(2999),
C
C NTMP = NP-3
C NI = NTMP/2
C DO 90 I=1,NI
C     TIMP(I) = 0.
C     PIMP(I) = 0.
C 90 CONTINUE
C IJ = 0
C SUMIMP = 0.
C DO 80 J=3,NTMP,2
C     IJ = IJ+1
C     TIMP(IJ) = TTIM(J)
C     AREA = (PRESS(J-1)+4.*PRESS(J)+PRESS(J+1))*DT/3.
C     SUMIMP = SUMIMP+AREA
C     PIMP(IJ) = SUMIMP
C 80 CONTINUE
C RETURN
C END
C
C SUBROUTINE FILTER(DT,NP)
C ****
C THIS SUBROUTINE FILTERS THE INPUT PRESSURE HISTORY
C (DATA OR SPEICHER-BRODE). IT USES THE DIFFERENCE
C EQUATIONS DERIVED FOR A SECOND ORDER BUTTERWORTH
C FILTER AS PRESENTED BY STEARNS, 1975.
C ****
C
C COMMON /THIST/ TTIM(6000),PRESS(6000),TIMP(2999),PIMP(2999),
C
C COMMON /COUNT/ ICOUNT,IOPT,LFILT
C COMMON /FILT/ IFILT,FLO(7),PFDMX(7),PFBMX(7)
C DATA LFILT/0/
C PI = 3.1415927
C S2 = SQRT(2.)
C LFILT = LFILT+1

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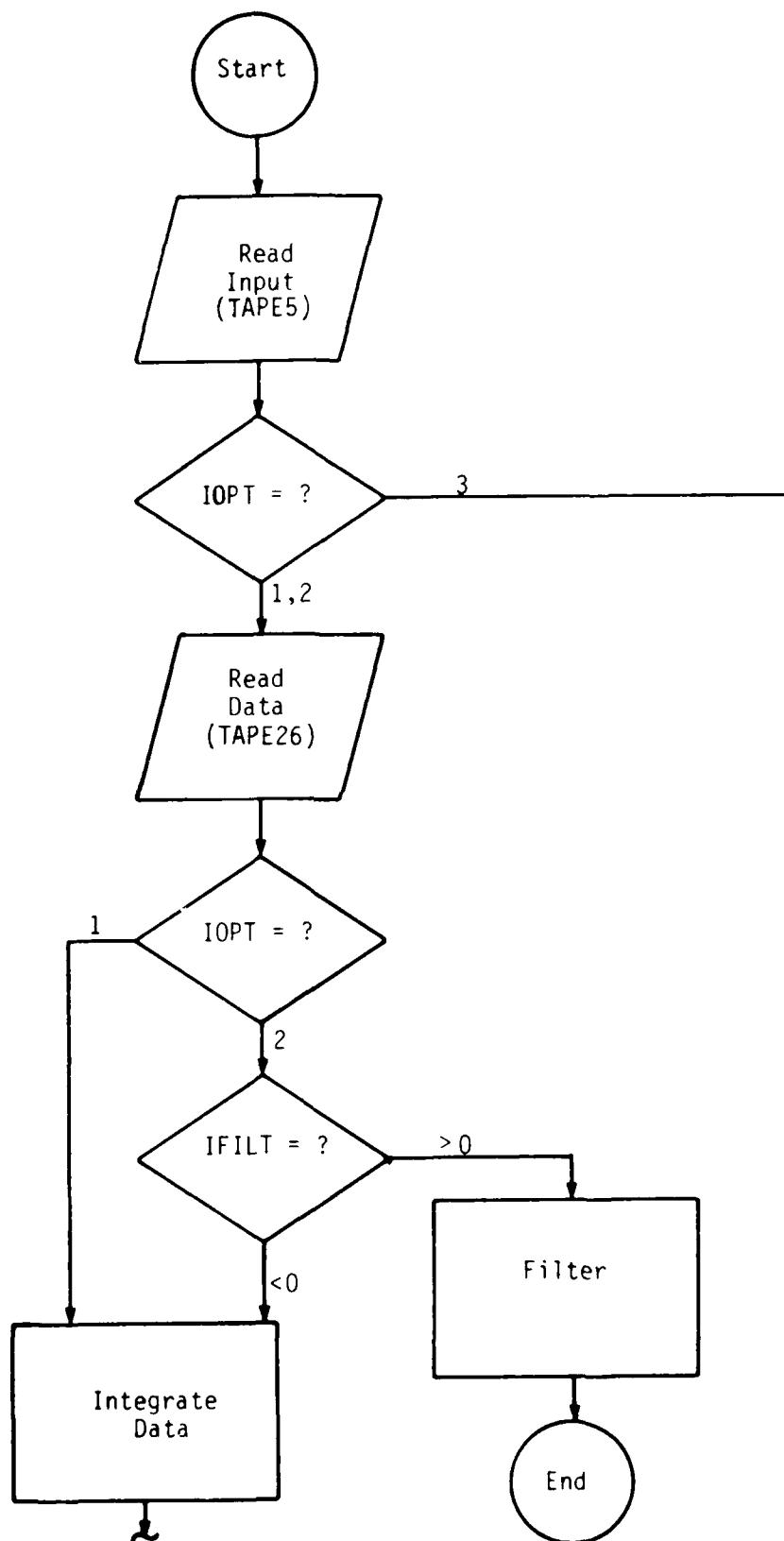
C
C      LOW PASS FILTER COEFFICIENTS
C
C      AT = TAN(PI-FLO(LFILT)*DT)
C      AT2 = AT*AT
C      A1 = 1.+S2*AT+AT2
C      A = AT2/A1
C      B1 = 2.-(AT2-1.)
C      B = B1/A1
C      C1 = 1.-S2*AT+AT2
C      C = C1/A1
C      FAC = 1.

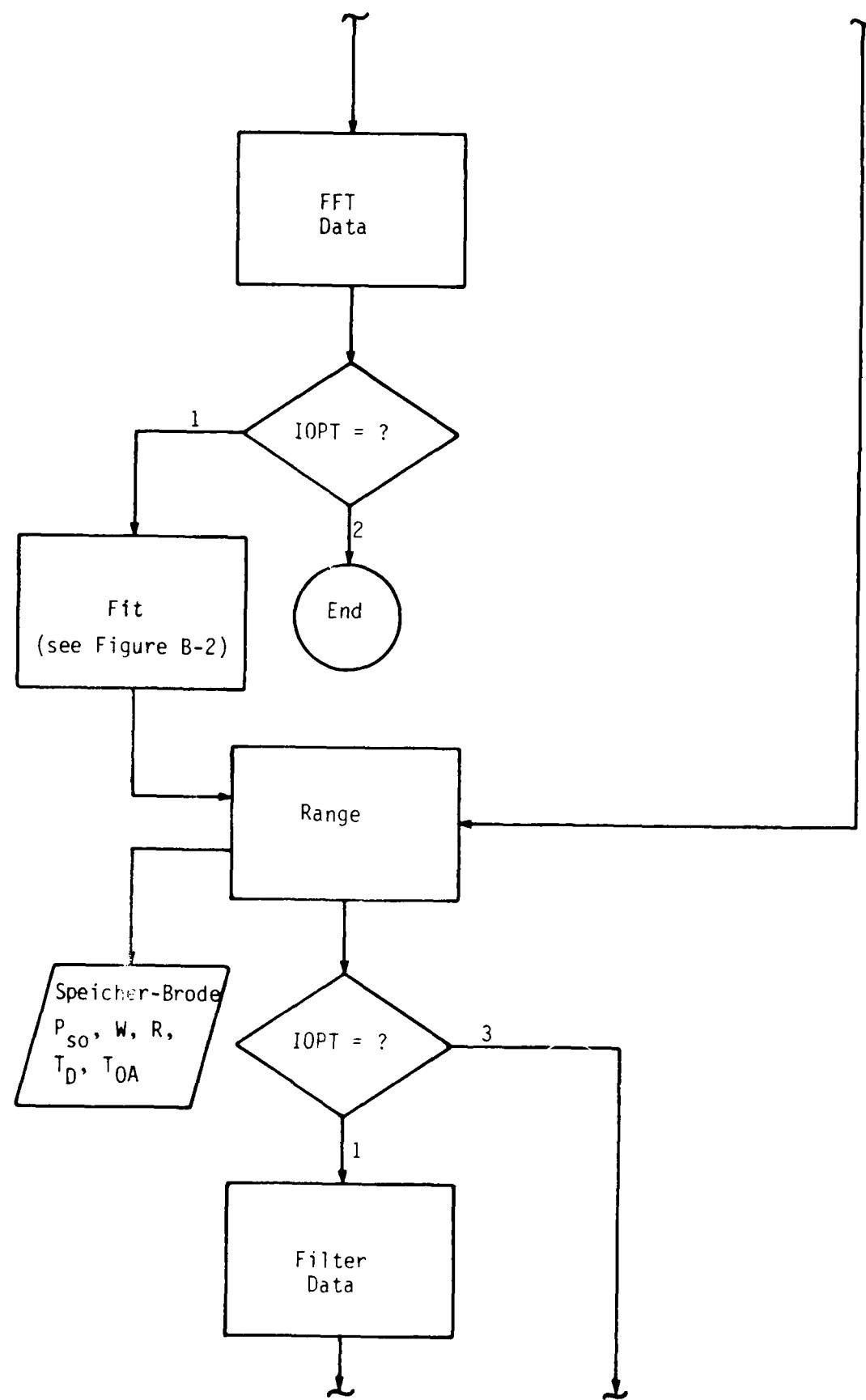
C      CALCULATE THE FILTERED HISTORY
C
150 PFILT(1) = A*PRESS(1)
C      PFILT(2) = A*(PRESS(2)+2.*FAC*PRESS(1))-B*PFILT(1)
C      DO 200 I=3,NP
C          PC = A*(PRESS(I)+2.*FAC*PRESS(I-1)+PRESS(I-2))
C          PFILT(I) = PC-B*PFILT(I-1)-C*PFILT(I-2)
200 CONTINUE
C      RETURN
C      END
C      SUBROUTINE FMAX(ARY,NA,XMN,XMX)
C      ****
C      THIS SUBROUTINE FINDS THE MAXIMUMS AND MINIMUMS
C      OF THE VARIOUS ARRAYS TO BE PLOTTED BY FOURPLT
C      ****
C
C      DIMENSION ARY(NA)
C
C      XMN = ARY(1)
C      XMX = ARY(1)
C      IF(NA.EQ.1) RETURN
C      DO 10 I=2,NA
C          IF(XMN.GT.ARY(I)) XMN = ARY(I)
C          IF(XMX.LT.ARY(I)) XMX = ARY(I)
10    CONTINUE
C
C      RETURN
C      END

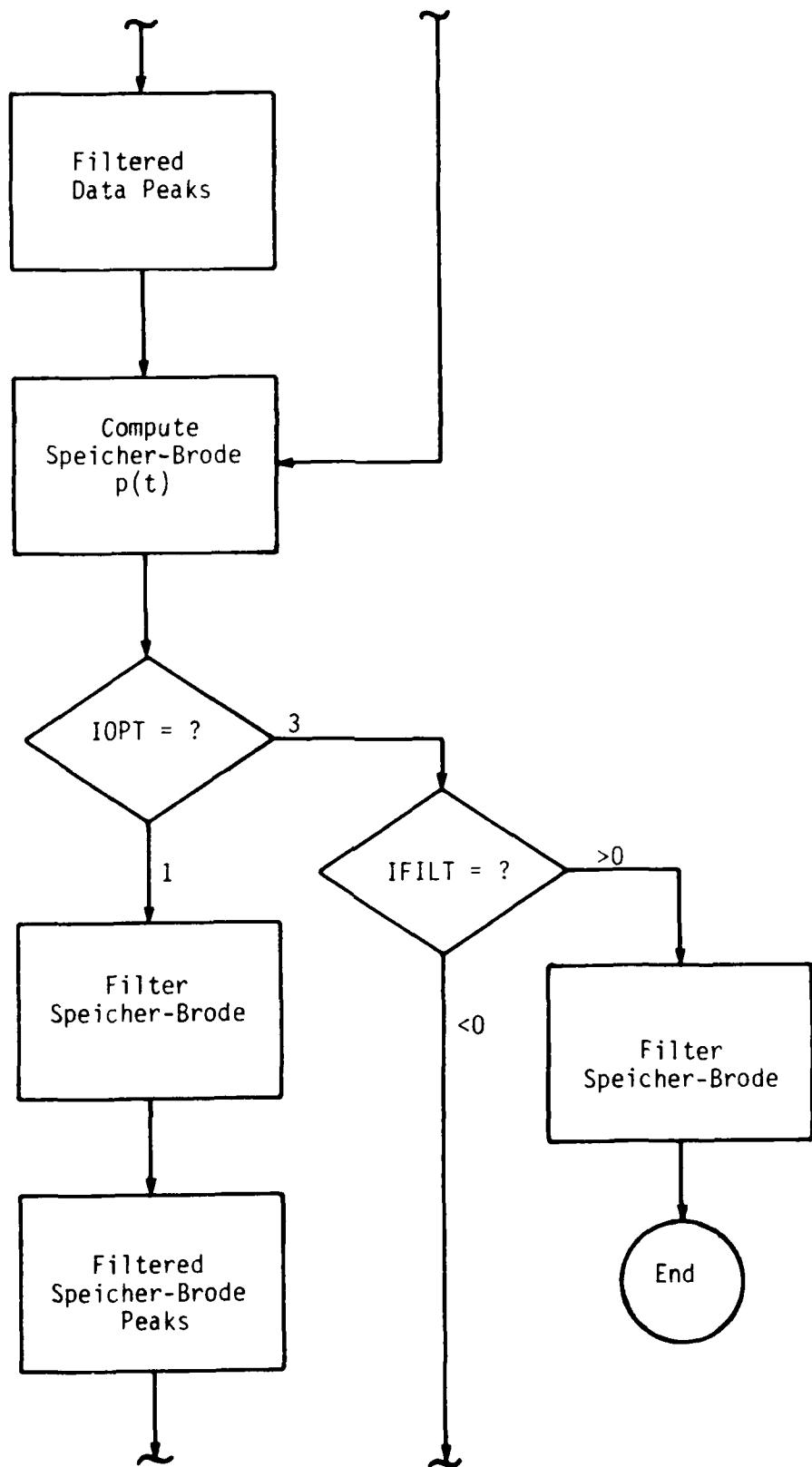
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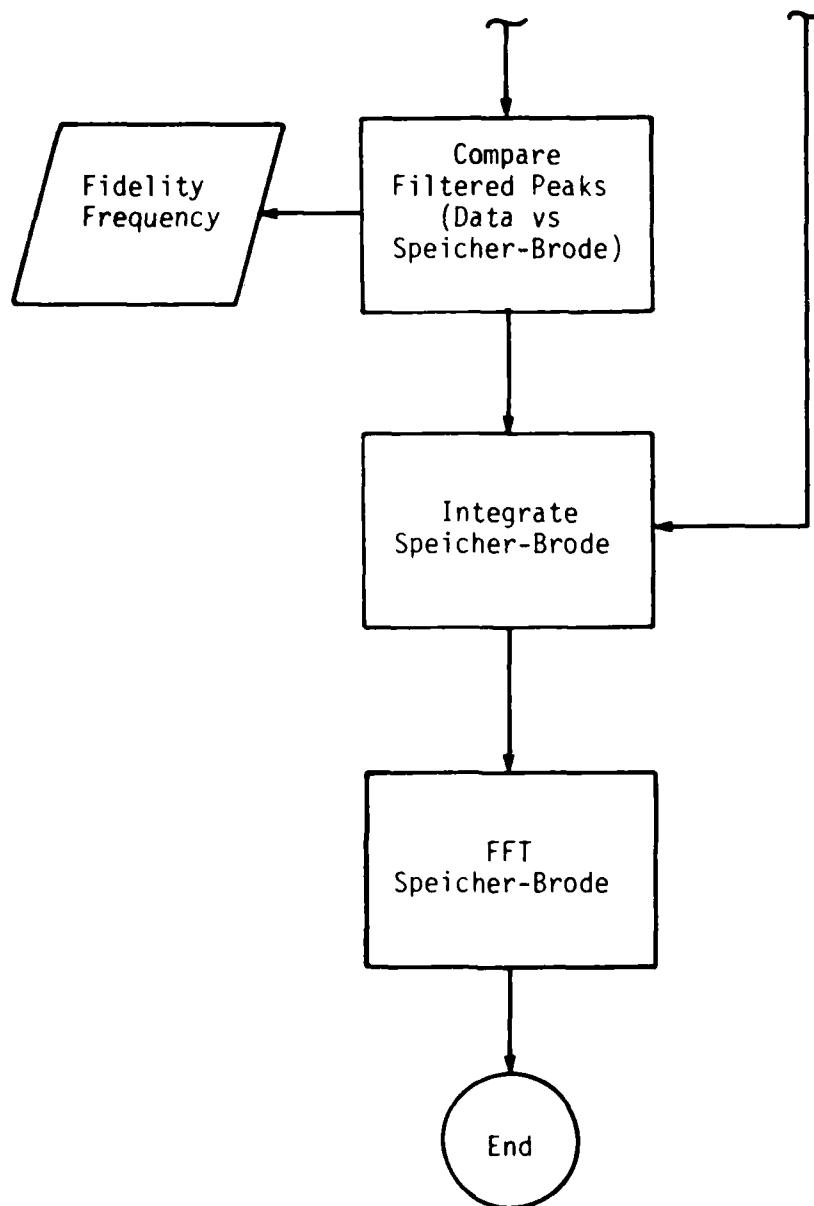
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APPENDIX B  
FLOW CHART OF PROGRAM FOURFIT

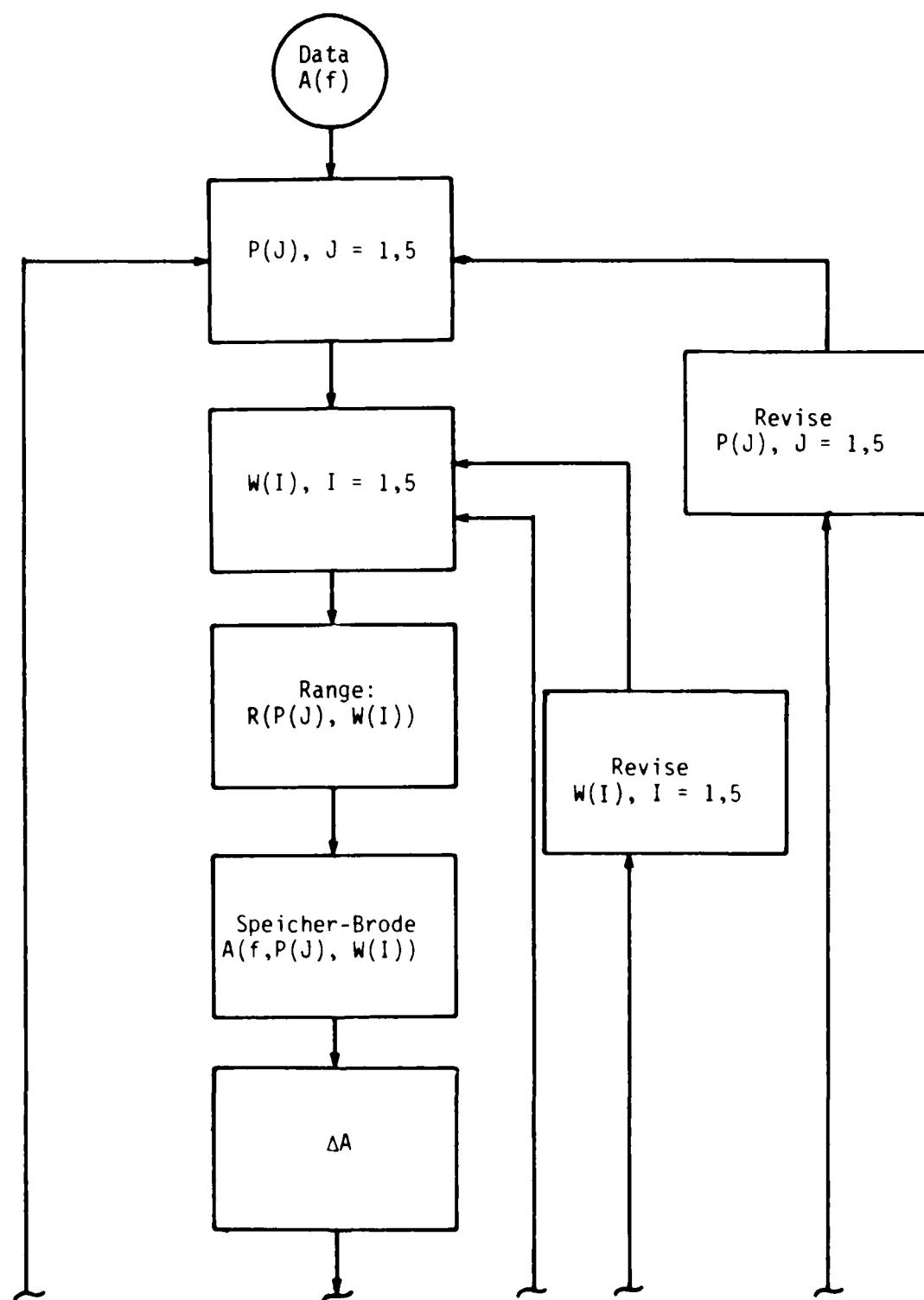


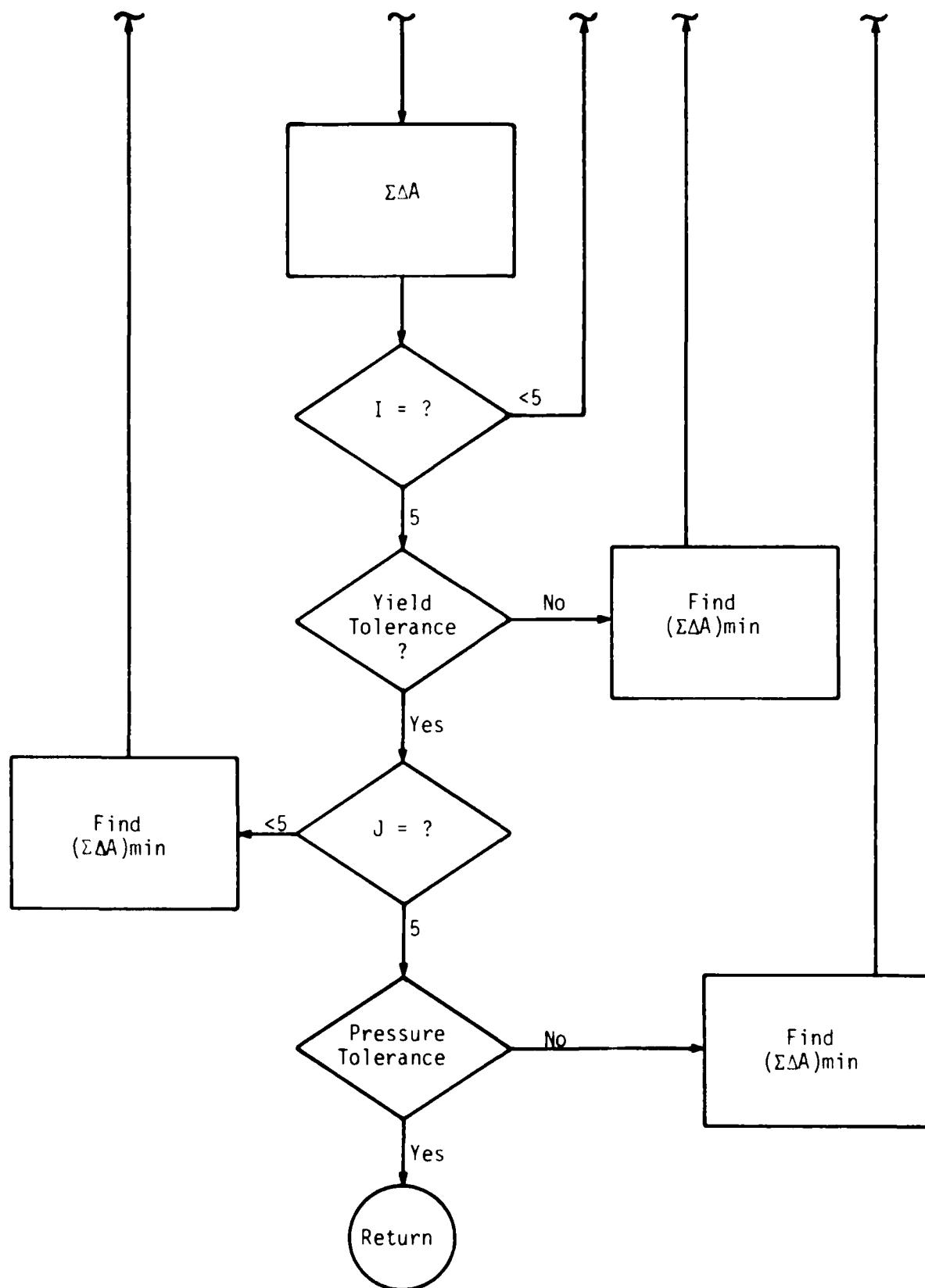






APPENDIX C  
FLOW CHART OF SUBROUTINE FIT





APPENDIX D  
LISTING OF PROGRAM FOURPLT

```

PROGRAM FOURPLT(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,
                 TAPE9,PLOT)
C *****  

C PROGRAM FOURPLT WAS WRITTEN TO PLOT THE RESULTS OF  

C PROGRAM FOURFIT. IT READS INPUT ON ASSIGNED FILE TAPE22  

C AND PLOTS SPEICHER-ERODE OR DATA PRESSURE AND IMPULSE  

C HISTORIES AND FOURIER AMPLITUDE SPECTRA OR PLOTS  

C OVERLAYS IN THESE SAME DOMAINS OF A DATA TRACE AND ITS  

C BEST FIT SPEICHER-BRODE AS DETERMINED BY FOURFIT.  

C WRITTEN BY J. C. PARTCH AND D. W. STEEDMAN, APPLIED  

C RESEARCH ASSOC., INC., ALBUQUERQUE, NM, FEB 1984.  

C *****  

COMMON /ESTIM/ PSDI,WI,PP,W13,PSOF,WF,FSO
COMMON /PEAK / DP,TA,PSO,ALPF
COMMON /THIST/ RSKFT,YS,S,XM
COMMON /FILT / IFILT,ITYPE,FLO(7),FHI(7),PFDMX(7),PFBMX(7)
COMMON /COUNT/ ICOUNT,IOPT,LFILT
COMMON /PLOTV/ ITL(B),ISTL(B),IDB
DIMENSION XARY(6000),YARY(6000)

C
      CALL GPLOT(1HU,7HARAARDS,7)
      CALL BGNPL(-1)
      READ(9,100) IOPT,IFILT
100   FORMAT(2I5)
      IF(IOPT.EQ.3) GO TO 200
      READ(9,120) (ITL(I),I=1,8)
120   FORMAT(8A10)
      IF(IOPT.NE.2) GO TO 200

C
C      OPTION 2 (DATA ONLY)
C
C      READ PRESSURE-TIME PAIRS
C      OR FILTERED PRESSURE-TIME PAIRS
      READ(9,130) NEPTS,XPMN,XPMX,YPMN,YPMX
130   FORMAT(15.4E15.8)
      DO 135 IF=1,7
      IF(IFILT.LT.0) GO TO 128
      READ(9,125) IFLAG
125   FORMAT(15)
      IF(IFLAG.LT.0) GO TO 112
      READ(9,127) FLO(IF)
      READ(9,172) YPMN,YPMX
127   FORMAT(F10.0)
128   READ(9,140) (XARY(K),K=1,NEPTS)
      READ(9,140) (YARY(L),L=1,NEPTS)
140   FORMAT(10E15.8)
      CALL PLOTTER(XARY,YARY,NEPTS,XPMN,XPMX,YPMN,YPMX,1,1,2,1,2)
      CALL ENDPL(-1)
      IF(IFILT.LT.0) GO TO 144
135   CONTINUE
112   CALL GDONE
      STOP 11

C
C      READ IMPULSE-TIME PAIRS FOR OPTION 2
144   READ(9,145) ITL(5),ITL(6)
      READ(9,130) NEI,XIMN,XIMX,YIMN,YIMX
      READ(9,140) (XARY(M),M=1,NEI)
      READ(9,140) (YARY(N),N=1,NEI)
145   FORMAT(2A10)
      CALL PLOTTER(XARY,YARY,NEI,XIMN,XIMX,YIMN,YIMX,1,1,3,1,3)
      CALL ENDPL(-1)

C
C      READ AMPLITUDE-FREQUENCY PAIRS FOR OPTION 2
      READ(9,254) ITL(5),ITL(6),ITL(7)
      READ(9,130) NEF,XFMN,XFMX,YFMN,YFMX
      READ(9,140) (XARY(II),II=1,NEF)
      READ(9,140) (YARY(UU),UU=1,NEF)
      CALL PLOTTER(XARY,YARY,NEF,XFMN,XFMX,YFMN,YFMX,2,5,4,4,3)
      CALL ENDPL(-1)
      CALL GDONE
      STOP 777

```

```

C
C      OPTION 1 (OVERLAY) AND OPTION 3 (SPEICHER-BRODE)
200 READ(9,205) PSDF,WF
      READ(9,207) DP,TA,RSKFT
205 FORMAT(2E15.8)
207 FORMAT(3E15.8)
      IF(IOPT.NE.1) GO TO 765
      READ(9,120) (1STL(KK),KK=1,8)

C      READ PRESSURE-TIME PAIRS (DATA)
      READ(9,130) NEPTS,XPMN,XPMX,YPMN,YPMX
      READ(9,140) (XARY(IT),IT=1,NEPTS)
      READ(9,140) (YARY(IW),IW=1,NEPTS)
      READ(9,766) ALPF
766 FORMAT(F10.0)
      CALL PLOTTER(XARY,YARY,NEPTS,XPMN,XPMX,YPMN,YPMX,1,1,2,1,2)

C      READ PRESSURE-TIME PAIRS OR FILTERED
C      PRESSURE-TIME PAIRS (SPEICHER-BRODE)
765 IF(IOPT.EQ.3) READ(9,120) (ITL(IR),IR=1,8)
      READ(9,160) NPPTS
160 FORMAT(I5)
      IF(IOPT.NE.3) GO TO 768
      READ(9,170) XPMN,XPMX,YPMN,YPMX
170 FORMAT(4E15.8)
      XPMX = XPMX/4.
      NPPTS = NPPTS/4.
768 DO 234 MF=1,7
      IF(IOPT.EQ.1 .OR. IFILT.LT.0) GO TO 171
      READ(9,125) JFLAG
      IF(JFLAG.LT.0) GO TO 236
      READ(9,127) FLO(MF)
      READ(9,172) YPMN,YPMX
172 FORMAT(2E15.8)
171 READ(9,140) (XARY(LL),LL=1,NPPTS)
      READ(9,140) (YARY(MN),MN=1,NPPTS)

C      PLOT SPEICHER-BRODE ONLY
C      IF(IOPT.EQ.3) CALL PLOTTER
C          (XARY,YARY,NPPTS,XPMN,XPMX,YPMN,YPMX,1,1,2,1,2)

C      OVERLAY
C      IF(IOPT.EQ.1) CALL PLOTTER
C          (XARY,YARY,NPPTS,XPMN,XPMX,YPMN,YPMX,-1,1,2,1,2)
C          CALL ENDPL(-1)
      IF(IOPT.EQ.1 .OR. IFILT.LT.0) GO TO 264

234 CONTINUE
236 CALL GDONE
      STOP22

C
C      IMPULSE
264 IF(IOPT.EQ.3) GO TO 280

C      READ IMPULSE-TIME PAIRS (DATA)
      READ(9,145) ITL(5),ITL(6)
      READ(9,130) NEI,XIMN,XIMX,YIMN,YIMX
      READ(9,140) (XARY(NN),NN=1,NEI)
      READ(9,140) (YARY(MN),MN=1,NEI)
      CALL PLOTTER(XARY,YARY,NEI,XIMN,XIMX,YIMN,YIMX,1,1,3,1,3)

C      READ IMPULSE-TIME PAIRS (SPEICHLR-BRODE)
280 READ(9,160) NIPTS
      IF(IOPT.EQ.3) READ(9,254) ITL(3),ITL(4),ITL(5)
254 FORMAT(3A10)
      IF(IOPT.EQ.3) READ(9,170) XIMN,XIMX,YIMN,YIMX
      READ(9,140) (XARY(IJ),IJ=1,NIPTS)
      READ(9,140) (YARY(JI),JI=1,NIPTS)

C      PLOT SPEICHER-BRODE ONLY
C      IF(IOPT.EQ.3) CALL PLOTTER
C          (XARY,YARY,NIPTS,XIMN,XIMX,YIMN,YIMX,1,1,3,1,3)

C      OVERLAY
      NIPTS=NIPTS-1
      IF(IOPT.EQ.1) CALL PLOTTER
C          (XARY,YARY,NIPTS,XIMN,XIMX,YIMN,YIMX,-1,1,3,1,3)
      CALL ENDPL(-1)

```

```

C
C      FOURIER AMPLITUDE
C      IF(IOPT.EQ.3) GO TO 340
C
C      READ AMPLITUDE-FREQUENCY PAIRS (DATA)
C      READ(9,254) ITL(5),ITL(6),ITL(7)
C      READ(9,130) NEF,XFMN,XFMX,YFMN,YFMX
C      READ(9,140) (XARY(KJ),KJ=1,NEF)
C      READ(9,140) (YARY(JK),JK=1,NEF)
C      CALL PLDTTER(XARY,YARY,NEF,XFMN,XFMX,YFMN,YFMX,2,5,4,4,3)
C
C      READ AMPLITUDE-FREQUENCY PAIRS (SPEICHER-BRODE)
340  READ(9,160) NEF
      IF(IOPT.EQ.3) READ(9,256) ITL(3),ITL(4),ITL(5),ITL(6)
256  FORMAT(4A10)
      IF(IOPT.EQ.3) READ(9,170) XFMN,XFMX,YFMN,YFMX
      READ(9,140) (XARY(KL),KL=1,NBF)
      READ(9,140) (YARY(LK),LK=1,NBF)
C
C      SPEICHER-ERODE ONLY
C      IF(IOPT.EQ.3) CALL PLOTTER
C          (XARY,YARY,NBF,XFMN,XFMX,YFMN,YFMX,2,5,4,4,3)
C
C      OVERLAY
C      IF(IOPT.EQ.1) CALL PLOTTER
C          (XARY,YARY,NBF,XFMN,XFMX,YFMN,YFMX,-1,5,4,4,3)
C      CALL ENDPL(-1)
C      CALL GDONE
C      END
C      SUBROUTINE PLOTTER(XARY,YARY,NP,XMN,XMX,YMN,YMX,KIND,LBLX,LBLY,
C          NITSX,NITSY)
C
C      COMMON /ESTIM/ PSOI,W1,PP,W13,PSDF,WF,FSO
C      COMMON /PEAK / DP,TA,PSO,ALPF
C      COMMON /FILT / IFILT,ITYPE,FLO(7),FHI(7),PFDMX(7),PFBM(7)
C      COMMON /THIST/ RSKFT,YS,S,XM
C      COMMON /COUNT/ ICOUNT,IOPT,LFILT
C
C      COMMON /PLOTV/ ITL(8),ISTL(8),IDB
C      DIMENSION XARY(NP),YARY(NP),LABS(6,2),LEND(4,2),LABX(4),
C          LABY(4)
C      DATA (LABS(1,J),J=1,2) /10H          .10H      TIME   /
C      DATA (LABS(2,J),J=1,2) /10H          .10H      PRESSURE   /
C      DATA (LABS(3,J),J=1,2) /10H          .10H      IMPULSE   /
C      DATA (LABS(4,J),J=1,2) /10H          A,10H      AMPLITUDE   /
C      DATA (LABS(5,J),J=1,2) /10H          F,10H      FREQUENCY   /
C      DATA (LABS(6,J),J=1,2) /10H          .10H      /
C
C      DATA LEND(1) /10H(SEC)   /
C      DATA LEND(2) /10H(MIN)   /
C      DATA LEND(3) /10H(MIN-SEC) /
C      DATA LEND(4) /10H(HZ)    /
C      DATA LEND(5) /10H(RADIANS) /
C
C      DATA LFILT/O/
C
C      WRITE(6,2300) NP,XMN,XMX,YMN,YMX,KIND
2300  FORMAT(5X,* ENTERED PLOTTER *.*,
* *NP,XMN,XMX,YMN,YMX,KIND = *.*,I5,4(1X,F7.4),I5)
      CALL HEIGHT(0.1)
      IF(KIND.LT.0) GO TO 200
C
C      DO 10 I=1,2
C          LABX(I) = LABS(LBLX,I)
C          LABY(I) = LABS(LBLY,I)
10     CONTINUE
      LABX(3) = LEND(NITSX)
      LABY(3) = LEND(NITSY)
C
C      IF(KIND.EQ.2) GO TO 100
C
C      ***** IF KIND.EQ.1 THEN PLOT IS LINEAR-LINEAR *****
C
C      50 LINET = 0
      LINES = 0

```

```

C
C     CALL SCL1(XMN,XMX,XORG,XSTP,XEND)
C     CALL SCL1(YMN,YMX,YORG,YSTP,YEND)
C     WRITE(6,2303) XORG,XSTP,XEND,YORG,YSTP,YEND
2303 FORMAT(2X,•LINEAR PLOT •,6(2X,FB.4))
C     CALL RLINER(XORG,XSTP,XEND,YORG,YSTP,YEND,LABX,LABY)
C     CALL DRAWC(XARY,YARY,NP,LINE,LINE)
C     GO TO 400
C
C     ***** IF KIND.EQ.2 THEN PLOT IS LOG-LOG *****
C
100 LINET = 0
LINES = 0
C
C     CALL SCL2(XMN,XMX,XORG,XCYC,KIND)
C     IF(KIND.EQ.1) GO TO 50
C     CALL SCL2(YMN,YMX,YORG,YCYC,KIND)
C     IF(KIND.EQ.1) GO TO 50
C     WRITE(6,2305) XORG,XCYC,YORG,YCYC
2305 FORMAT(5X,•LOG-LOG PLOT •,4(2X,FB.4))
C     CALL LOGLLL(XORG,XCYC,YORG,YCYC,LAEX,LABY)
C     CALL DRAWC(XARY,YARY,NP,LINE,LINE)
C     GO TO 400
C
C     ***** IF KIND.LT.0 THEN PLOT AN OVERLAY *****
C
200 LINET = LINET+1
WRITE(6,2307)
2307 FORMAT(5X,• OVERLAY PLOT •)
CALL BLOFF(IDB)
CALL MESSAG(1STL,80,0,0,6,25)
CALL MESSAG(4HDATA,4,4,5,5,8)
CALL STRPT(5,2,5,8)
CALL CONNPT(5,8,5,8)
CALL MESSAG(4HFIT ,4,4,5,5,6)
CALL DASH
CALL STRPT(5,2,5,6)
CALL CONNPT(5,8,5,6)
CALL RESET(4HDASH)
C
C     CALL DRAWC(XARY,YARY,NP,LINE,LINE)
C     GO TO 900
C
400 IF(IOPT.EQ.1 .OR. IFILT.LT.0) GO TO 300
LFIILT=LFIILT+1
CALL MESSAG(15HLOW PASS FILTER,15,6,5,1,0)
CALL MESSAG(15HFCUTOFF (HZ) = .15,6,5,0,75)
CALL REALNO(FLO(LFIILT),0,8,2,0,75)
300 IF(IOPT.EQ.2) GO TO 900
CALL MESSAG(13HYIELD (KT) = .13,6,5,5,5)
CALL REALNO(WF,2,8,2,5,5)
CALL MESSAG(13HPSD (MP2) = .13,6,5,5,25)
CALL REALNO(PSDF,2,8,2,5,25)
CALL MESSAG(13HRANGE (KMI) = .13,6,5,5,0)
RRR = RSKFT*0.3048*(WF**0.333333)
CALL REALNO(RRR,5,8,2,5,0)
CALL MESSAG(19HPOS. PHASE (SEC) = .19,6,5,4,75)
DPP = DP*0.001*(WF**0.333333)
CALL REALNO(DPP,5,8,2,4,75)
CALL MESSAG(13HTOA (SEC) = .13,6,5,4,5)
TAA = TA*0.001*(WF**0.333333)
CALL REALNO(TAA,5,8,2,4,5)
IF(IOPT.NE.1) GO TO 900
WRITE(6,666) IOPT
666 FORMAT(2X,•++IOPT=•,15)
CALL MESSAG(20HLOW PASS FID (HZ) = .20,6,5,4,25)
CALL REALNO(ALPF,0,8,2,4,25)
C
900 CONTINUE
RETURN
END

```

```

SUBROUTINE FMAX(ARY,NA,XMN,XMX)
DIMENSION ARY(NA)

C
WRITE(6,2300)
2300 FORMAT(5X, *SUBROUTINE FMAX*)
XMN = ARY(1)
XMX = ARY(1)
IF(NA.EQ.1) RETURN
DO 10 I=2,NA
  IF(XMN.GT.ARY(I)) XMN = ARY(I)
  IF(XMX.LT.ARY(I)) XMX = ARY(I)
10  CONTINUE
C
RETURN
END
SUBROUTINE SCL1(XMN,XMX,AORG,ASTP,AMAX)
DIMENSION S(7)

C
***** FIND LINEAR SCALES *****
C
WRITE(6,2300) XMN,XMX
2300 FORMAT(5X, *SUBROUTINE SCL1    XMN,XMX = *,2(F8.4,2X))
SMIN = 0.00006
S(1) = 0.00012
S(2) = 0.00018
S(3) = 0.00024
S(4) = 0.00030
S(5) = 0.00036
S(6) = 0.00060
S(7) = 0.00120

C
DIF = XMX - XMN
IF(DIF.LT.S(1)) GO TO 90
5  CONTINUE
DO 10 I=1,7
  IU = I
10  IF(DIF.LT.S(I)) GO TO 30
DO 20 J=1,7
20  S(J) = S(J)*10.0
IF(S(1).GT.1.0E15) STOP111
GO TO 5
C
30 DMAX = S(IU)
DSTP = DMAX/6.0
C
      DETERMINE OFFSET
C
IF(XMN.LT.0.0) GO TO 60
DORG = 0.0
IF(XMN.LT.DSTP) GO TO 99
OFFSET = DSTP
35 OFFSET = OFFSET+DSTP
IF(XMN.GT.OFFSET) GO TO 35
DORG = OFFSET-DSTP
DMAX = DMAX+DORG
GO TO 99
C
60 OFFSET = 0.0
65 OFFSET = OFFSET-DSTP
IF(XMN.LT.OFFSET) GO TO 65
DORG = OFFSET
DMAX = DMAX+DORG
IF(XMN.LT.DMAX) GO TO 99
IF(IU.LT.7) DMAX = S(IU+1)
IF(IU.EQ.7) DMAX = S(1)*10.0
DSTP = DMAX/6.0
GO TO 50
C
      DIFFERENCE IS ZERO
C
90 CONTINUE
DORG = XMN-SMIN
DMAX = XMN+SMIN
DSTP = SMIN/3.0
C

```

```

00 AORG = DORG
  ASTP = DSTP
  AMAX = DMAX
  WRITE(6,2303) DORG,DSTP,DMAX
2303 FORMAT(5X,• LEAVING SCL1      •,3(F8.4,2X))
C
  RETURN
END
SUBROUTINE SCL2(XMN,XMX,AORG,ACYC,KIND)
C
C               SCALE FOR LOG-LOG PLOTS
C
  WRITE(6,2300) XMN,XMX
2300 FORMAT(5X,•ENTER SCL2      •,2(F8.4,2X))
  IF(XMN.LT.1.OE-8) GO TO 80
  IF(XMX.LT.1.OE-8) GO TO 81
C
  SMN = ALDG10(XMN)
  SMX = ALDG10(XMX)
  MN = IFIX(SMN)
  IF(SMN.LT.0.0) MN=MN-1
  MX = IFIX(SMX)
  AORG = 10.**MN
  DIF = (MX-MN)+1
  IF(MN.LT.0. AND. MX.LE.0) DIF = MX-MN
  ACYC = ABS(6.0/DIF)
  GO TO 90
C
  80 WRITE(6,1000) XMN
1000 FORMAT(5X,•XMN = •,E12.5,• A LINEAR PLOT WILL BE MADE. •)
  GO TO 82
  81 WRITE(6,1001) XMX
1001 FORMAT(5X,•XMX = •,E12.5,• A LINEAR PLOT WILL BE MADE. •)
  82 KIND = 1
C
  90 CONTINUE
  WRITE(6,2303) MN, MX, DIF, AORG, ACYC
2303 FORMAT(5X,•LEAVING SCL2      MN, MX, DIF, AORG, ACYC, 2I5, 3(1X,FB.4))
  RETURN
END
SUBROUTINE DRAWC(X,Y,NP,LINE,LINE)
  DIMENSION X(NP),Y(NP)
C
  WRITE(6,2300) NP,LINE,LINE
2300 FORMAT(5X,•ENTER DRAWC      NP,LINE,LINE = •,3I5)
  IF(LINE.LE.0) GO TO 10
  IF(LINE.EQ.1) CALL DASH
  IF(LINE.EQ.2) CALL CHNDOT
  IF(LINE.EQ.3) CALL CHNDSH
  IF(LINE.EQ.4) CALL DOT
C
  10 CALL CURVE(X,Y,NP,LINE)
C
  IF(LINE.LE.0) GO TO 99
  CALL RESET(3HALL)
  CALL HEIGHT(0.1)
C
  99 CONTINUE
  RETURN
END

```

```

SUBROUTINE RLINER(XORG,XSTP,XEND,YORG,YSTP,YEND,LABX,LABY)
COMMON /COUNT/ ICOUNT,IOPT,LFILT
COMMON /PLOTV/ ITL(8),ISTL(8),IDB
DIMENSION LABX(3),LABY(3)

C
      WRITE(6,2300)
2300 FORMAT(5X,*ENTERED RLINER.....*)
      CALL PAGE(10.0,0.5)
      CALL PHYSOR(1.0,1.0)
      CALL XNAME(LABX,30)
      CALL YNAME(LABY,30)
      CALL AREA2D(6.0,6.0)
      IF(IOPT.EQ.1) CALL BLREC(4.4,5.5,1.6,0.5,1.0)
      IF(IOPT.EQ.1) CALL BLKEY(IDB)
      CALL MESSAG(ITL,80,0.0,6.5)
      CALL GRAF(XORG,XSTP,XEND,YORG,YSTP,YEND)
      CALL DOT
      CALL GRID(1,1)
      CALL RESET(3HDOT)

C
      RETURN
      END

SUBROUTINE LOGLLL(XDR,XCY,YDR,YCY,LABX,LABY)
COMMON /COUNT/ ICOUNT,IOPT,LFILT
COMMON /PLOTV/ ITL(8),ISTL(8),IDB
DIMENSION LABX(3),LABY(3)

C
      WRITE(6,2300)
2300 FORMAT(5X,*ENTERED LOGLLL.....*)
      CALL PAGE(10.5,8.5)
      CALL PHYSOR(1.0,1.0)
      CALL XNAME(LABX,30)
      CALL YNAME(LABY,30)
      CALL AREA2D(6.0,6.0)
      IF(IOPT.EQ.1) CALL BLREC(4.4,5.5,1.6,0.5,1.0)
      IF(IOPT.EQ.1) CALL BLKEY(IDB)
      CALL MESSAG(ITL,80,0.0,6.5)
      CYC = XCY
      IF(YCY.LT.XCY) CYC = YCY
      CALL LOGLDG(XDR,CYC,YDR,CYC)
      CALL DOT
      CALL GRID(1,1)
      CALL RESET(3HDOT)

C
      RETURN
      END

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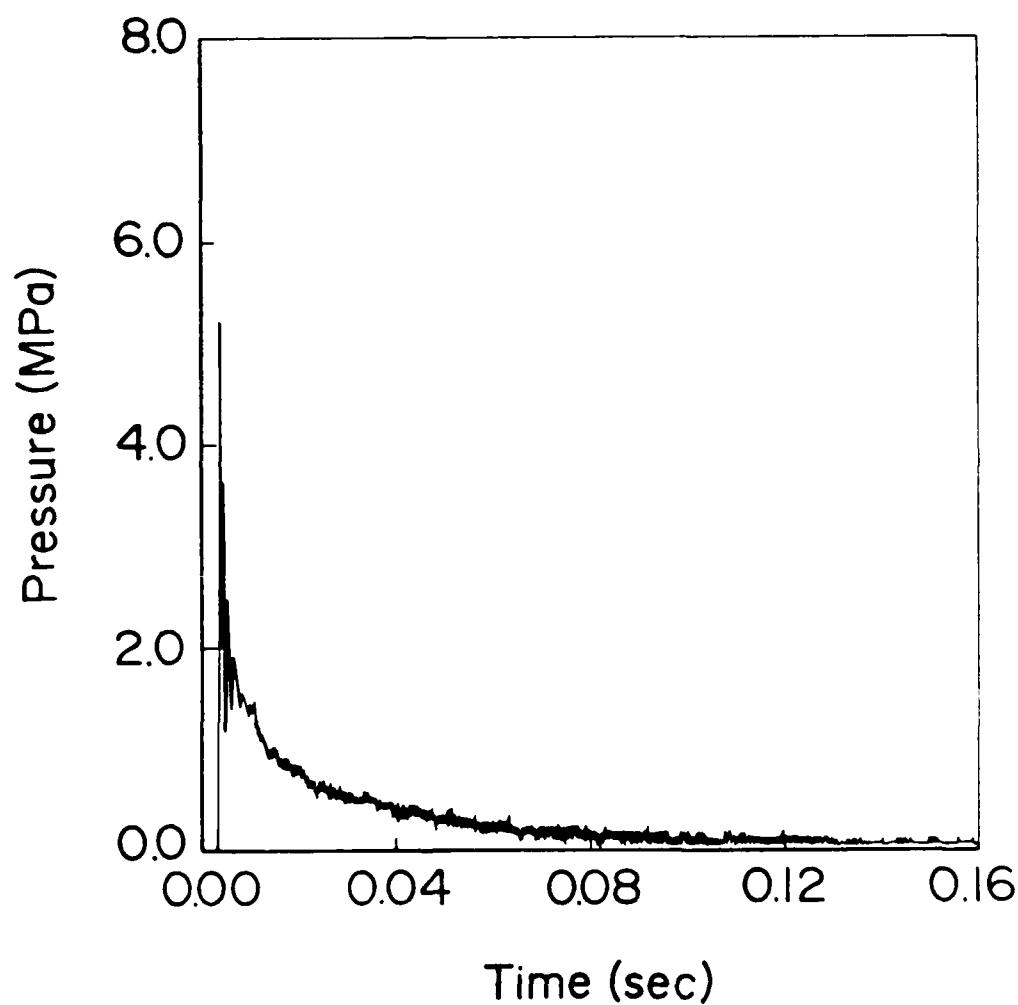


Figure 1. Typical HEST pressure history.

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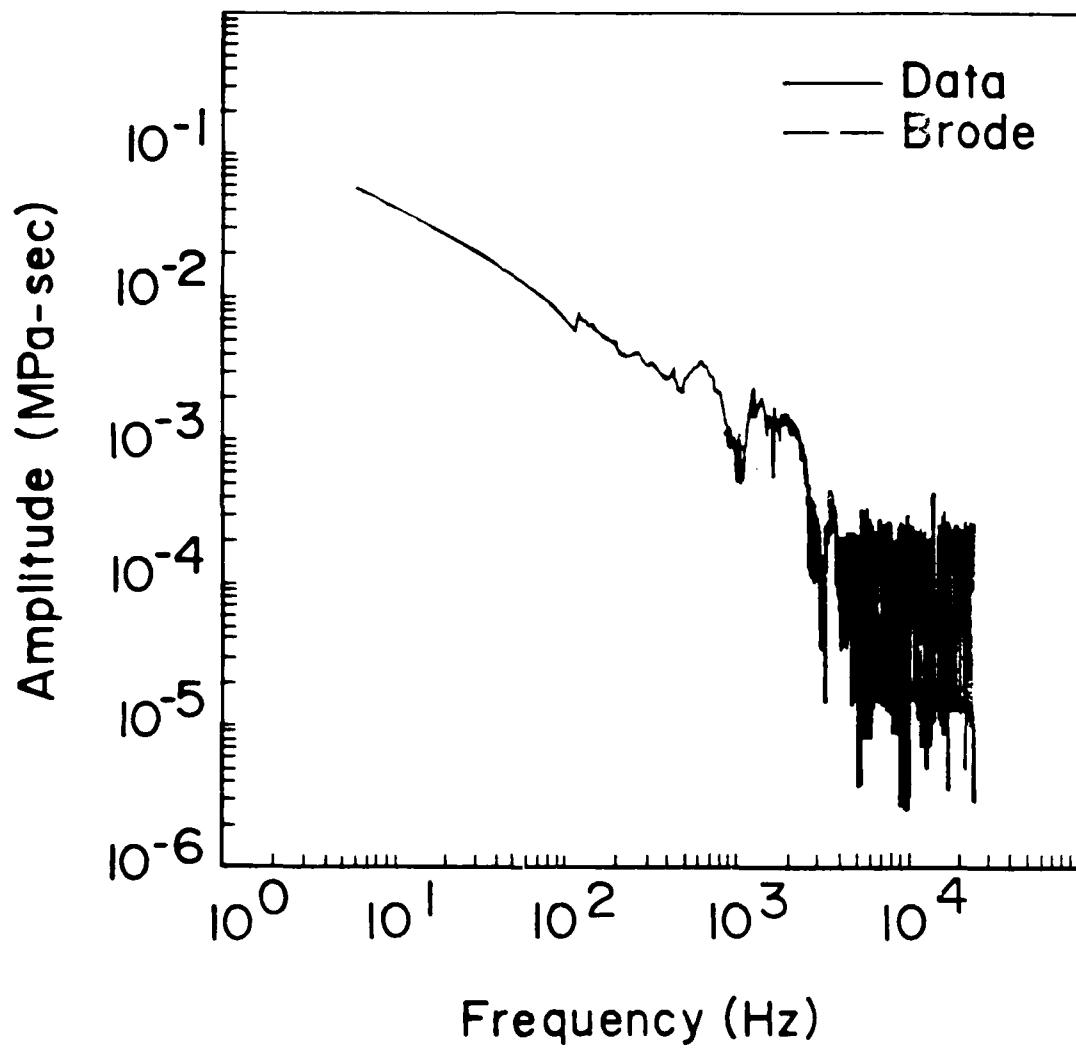


Figure 2. Fourier amplitude spectrum for typical HEST record.

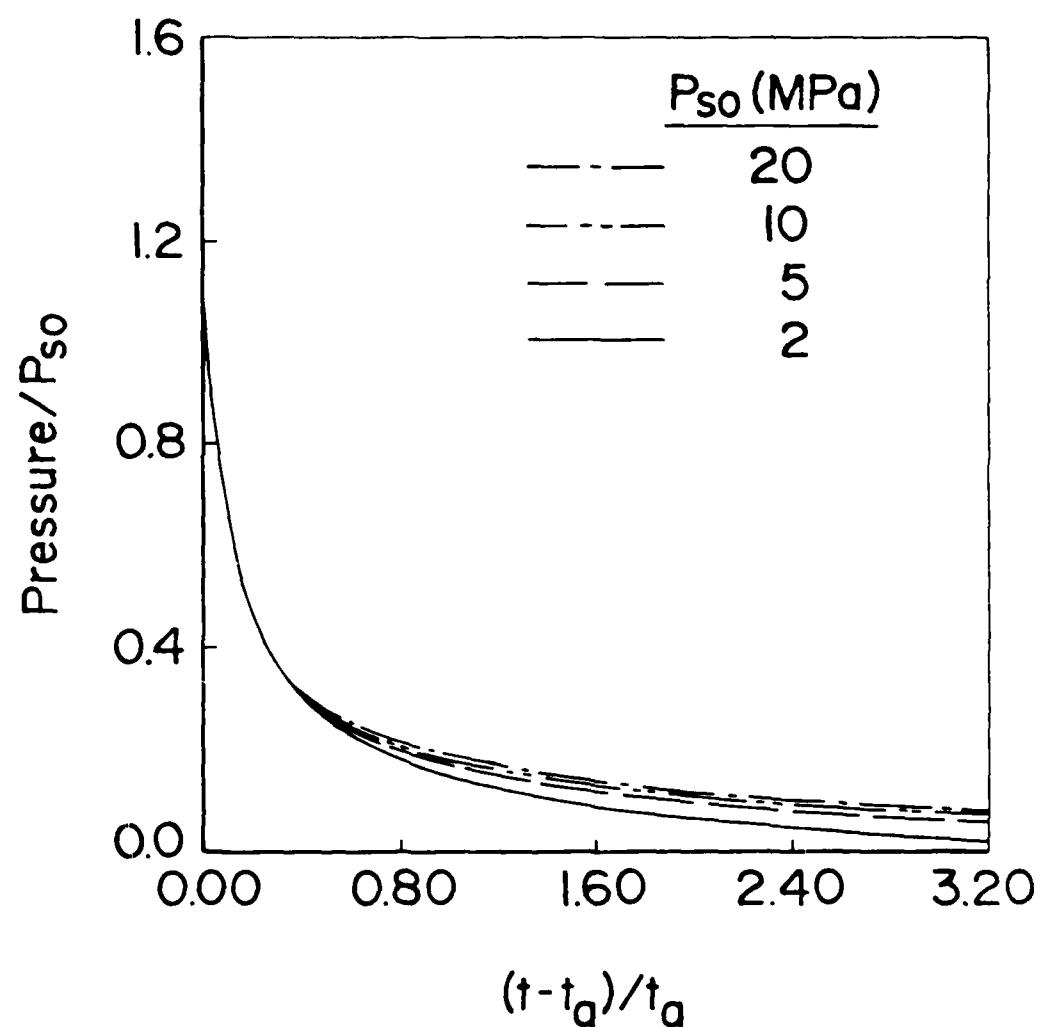


Figure 3. Normalized Brode pressure histories.

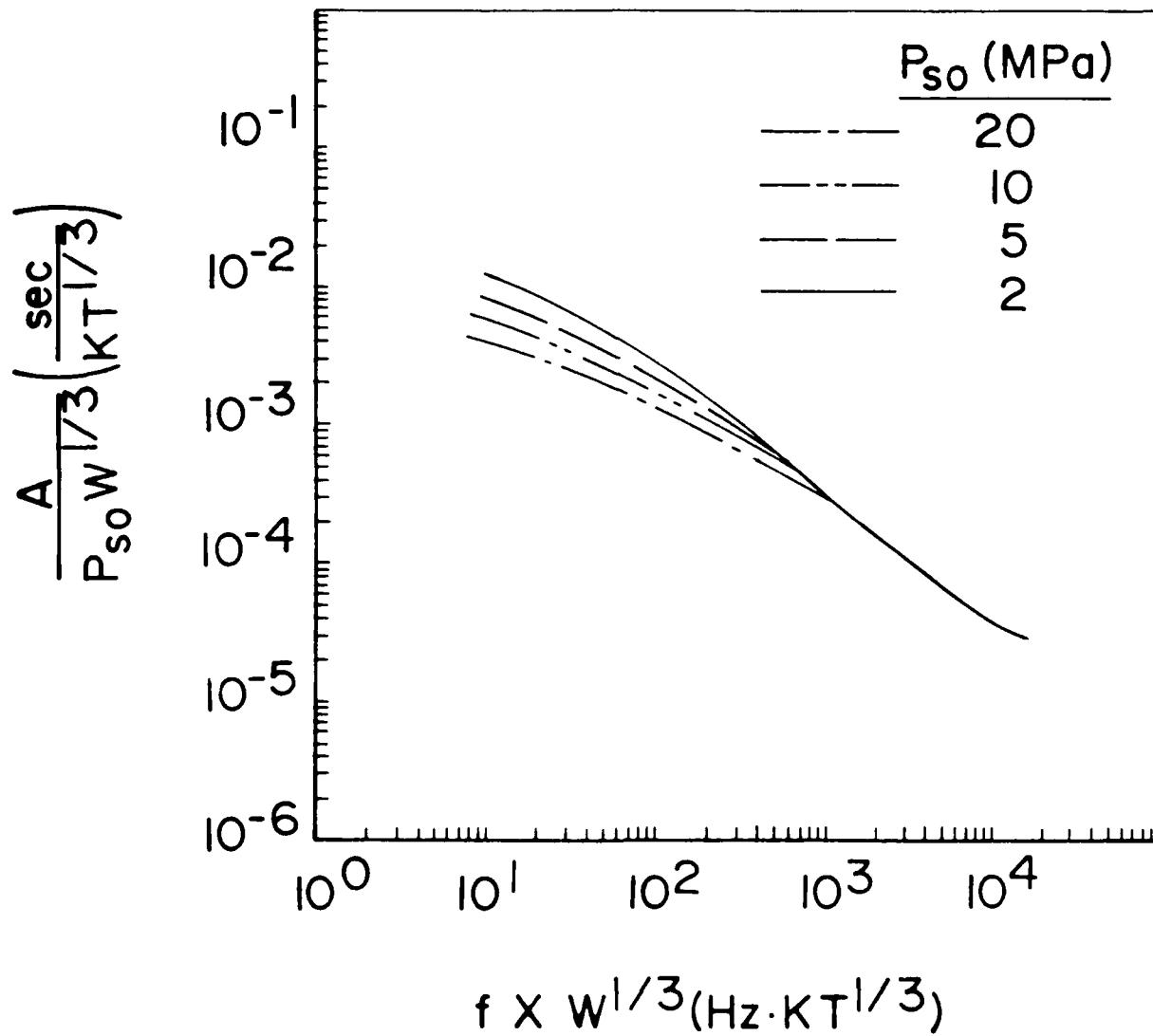


Figure 4. Normalized Brode Fourier amplitude spectra.

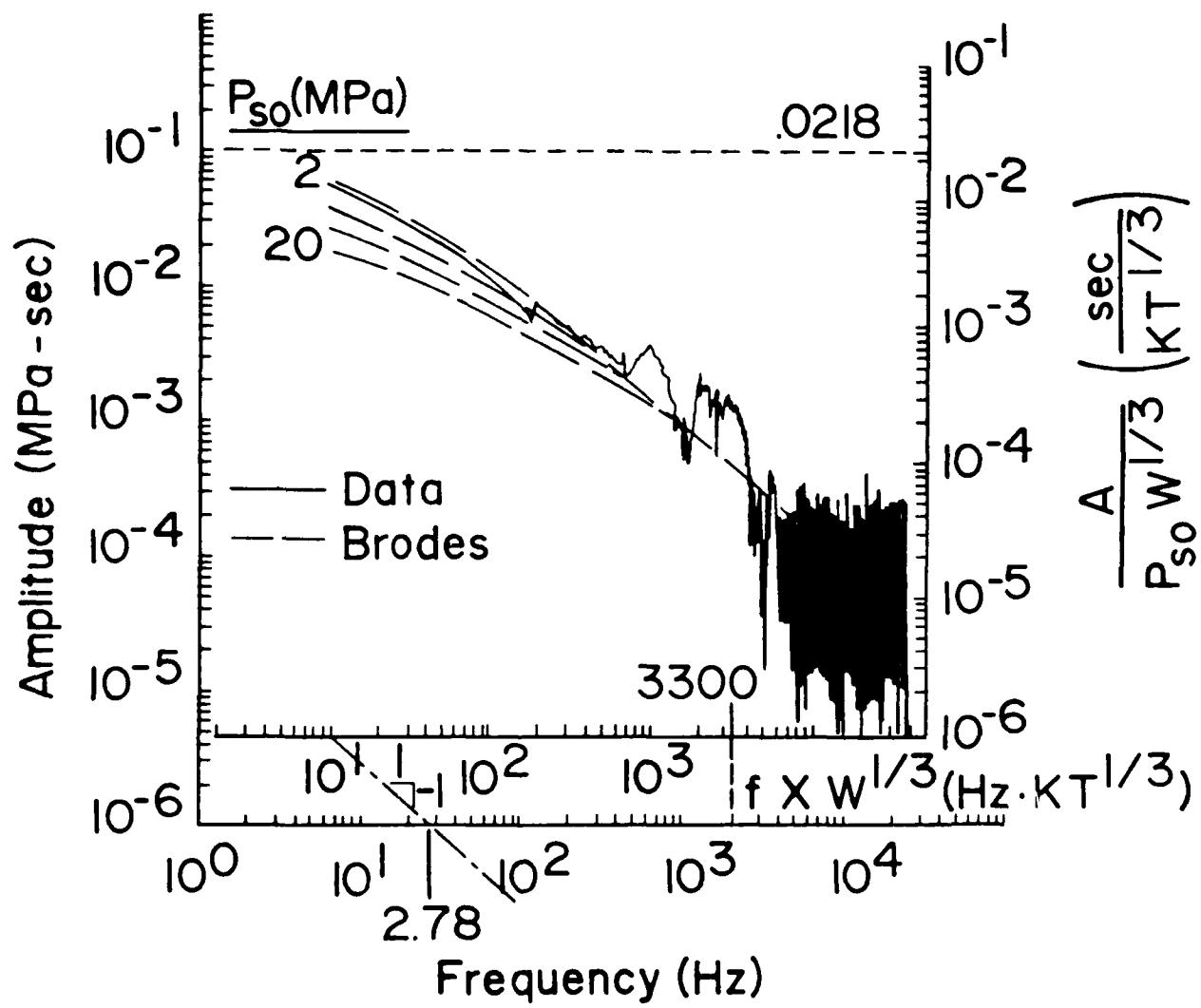


Figure 5. Overlay of first iteration fit to Fourier amplitude spectrum of the HEST record shown in Figure 1 with Brode spectra

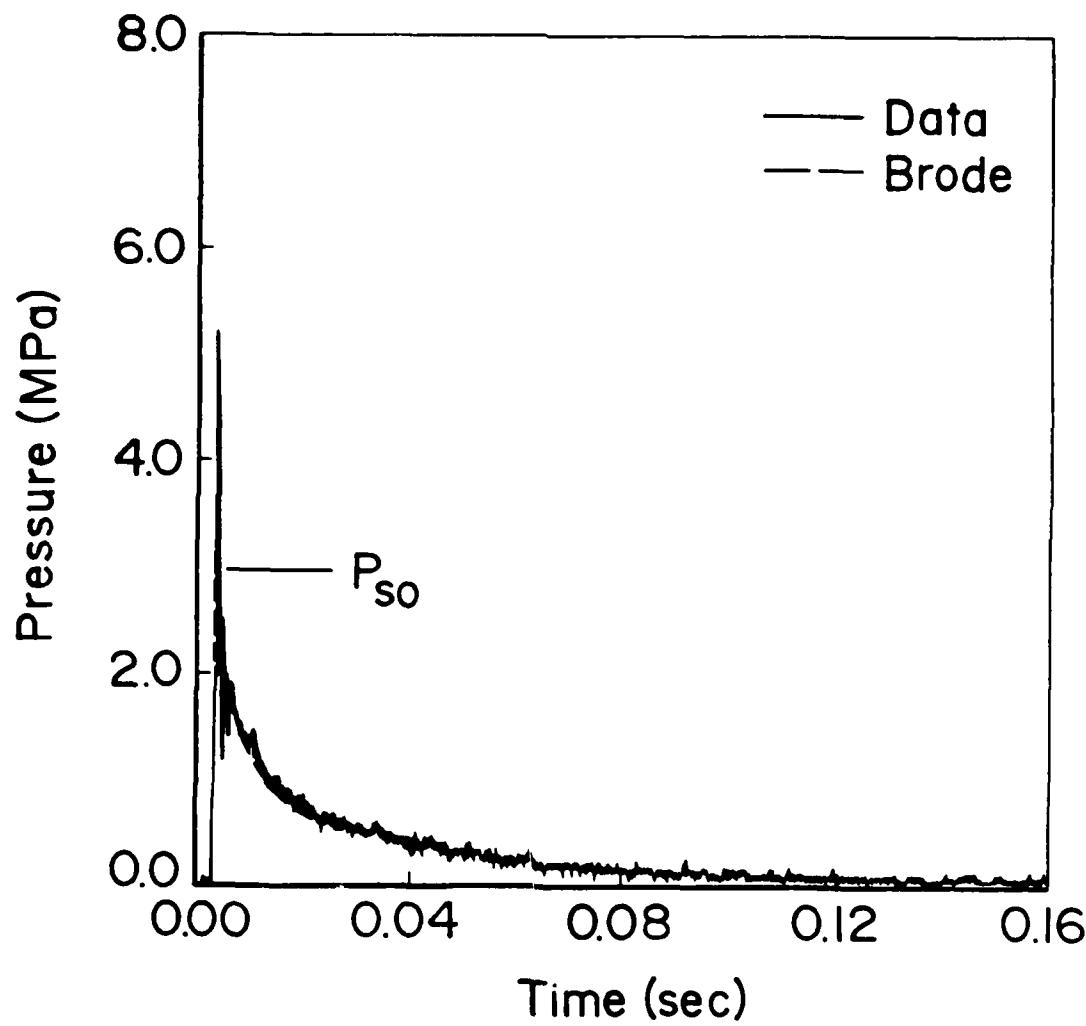


Figure 6. Pressure history for HEST record compared with final fit;  
 $P_{so} = 2.95 \text{ MPa}$ ,  $W = 5.05 \text{ KT}$ .

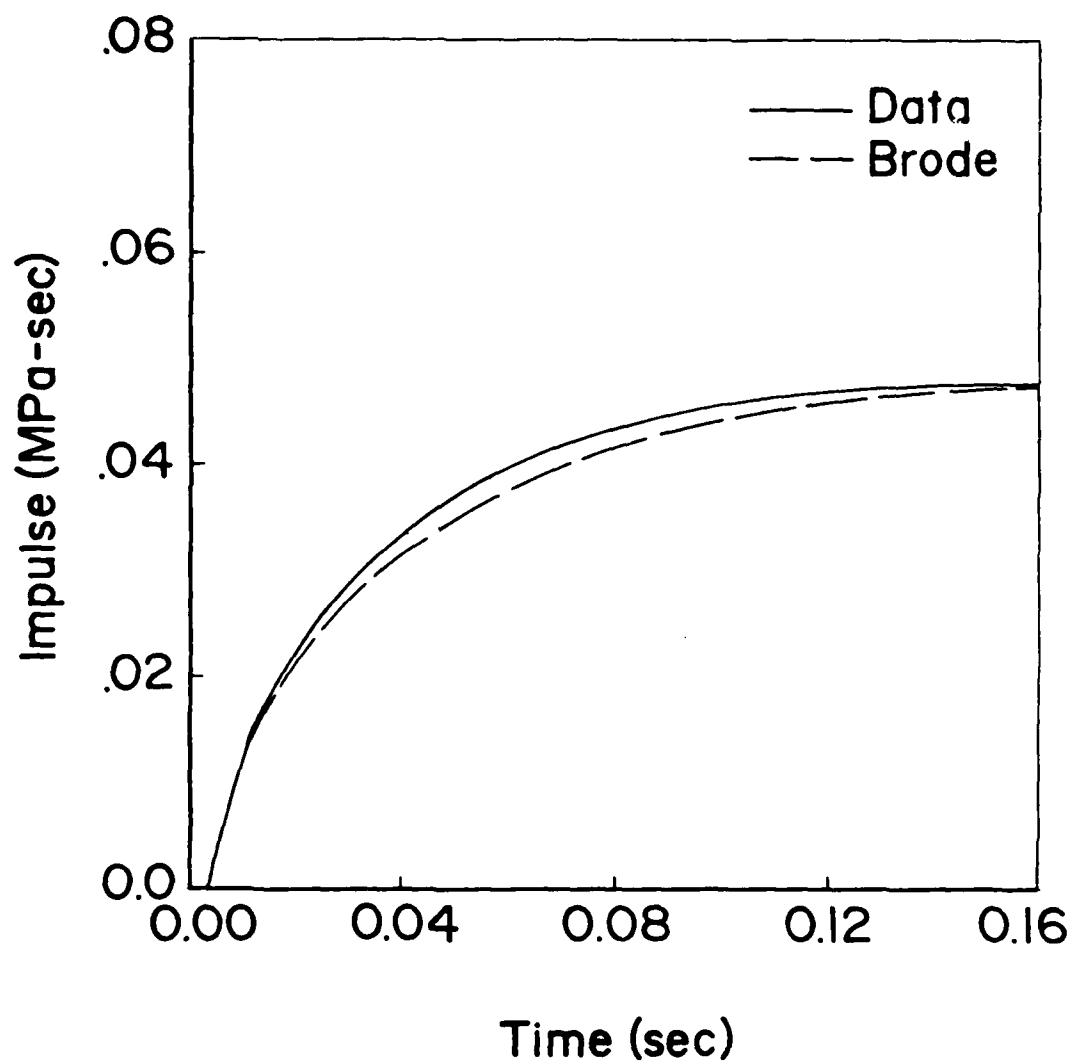


Figure 7. Impulse history for HEST record compared with final fit;  $P_{s0} = 2.95$  MPa,  $W = 5.05$  KT.

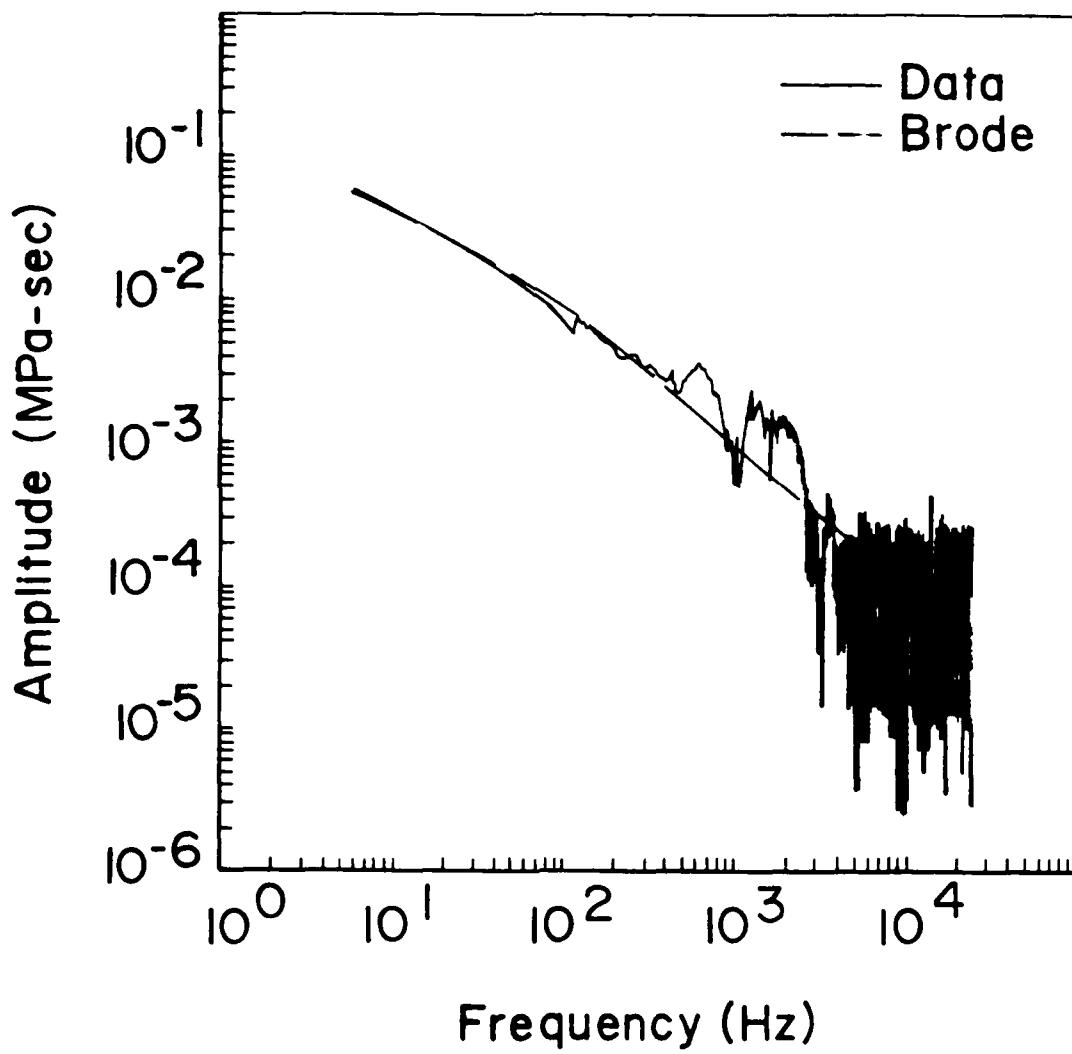


Figure 8. Fourier amplitude spectrum for HEST record compared with final fit;  $P_{s0} = 2.95$  MPa,  $W = 5.05$  KT.

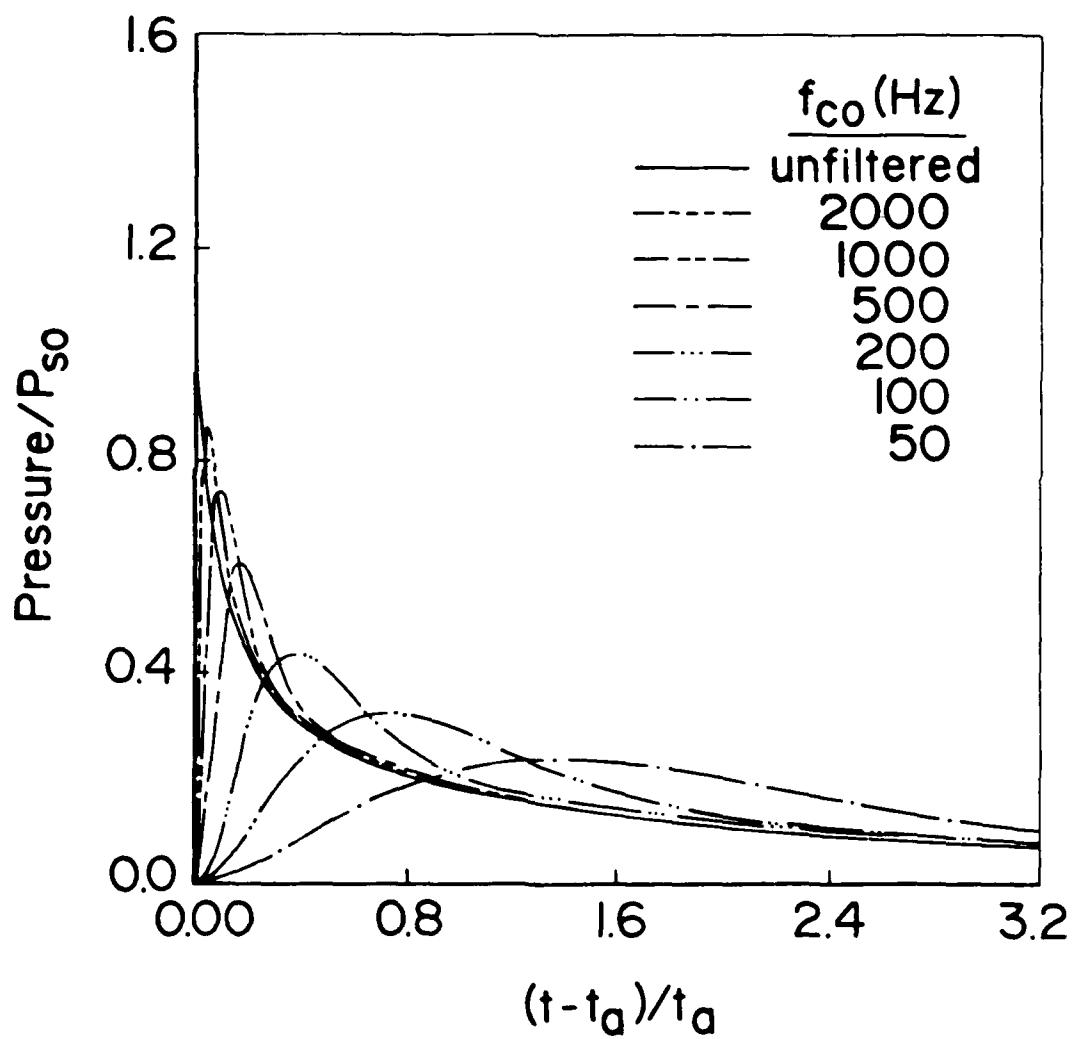


Figure 9. Normalized low pass filtered Brode pressure histories;  
 $P_{s0} = 10 \text{ MPa}$ .

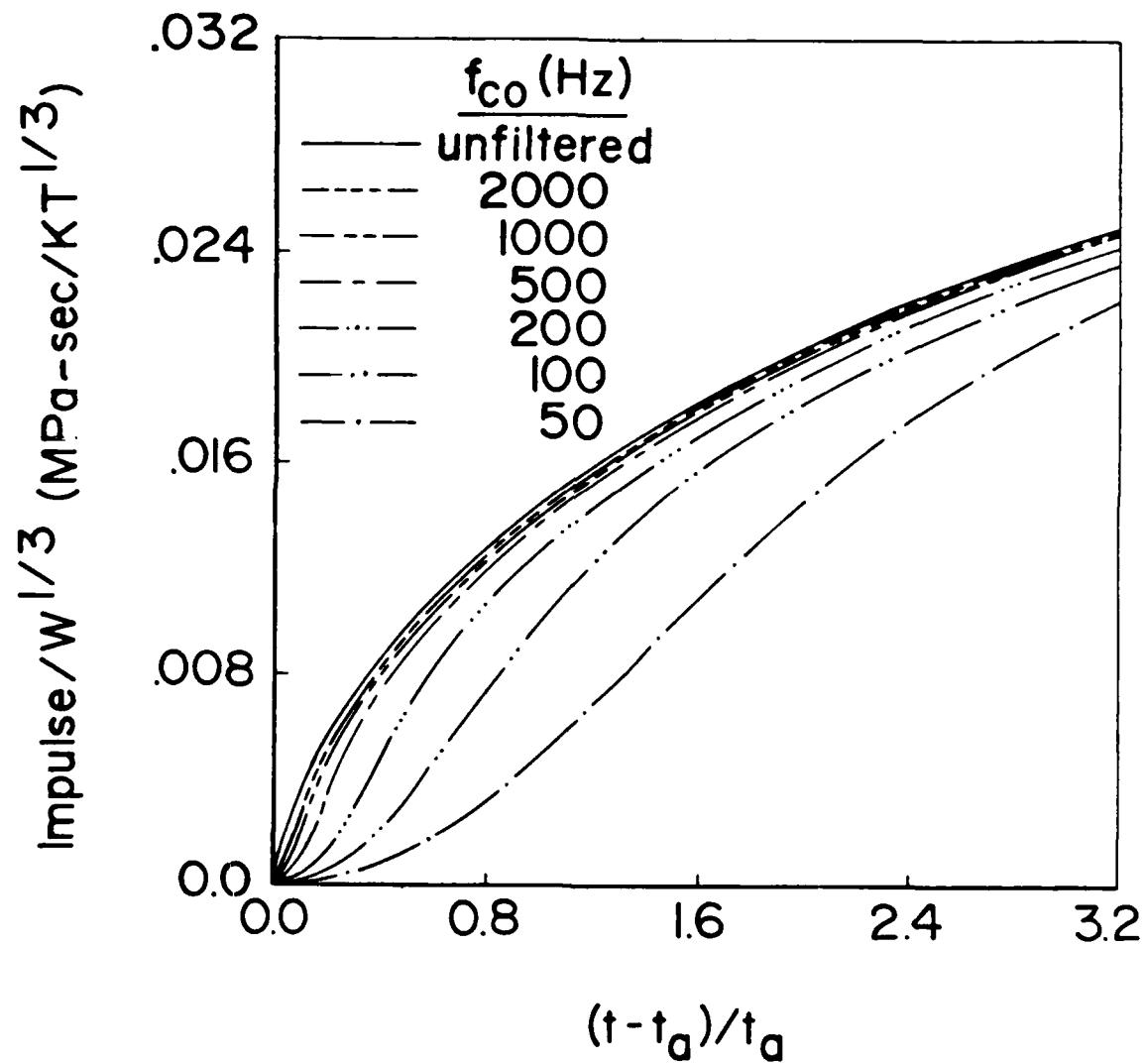


Figure 10. Normalized low pass filtered Brode impulse histories;  $P_{so} = 10$  MPa.

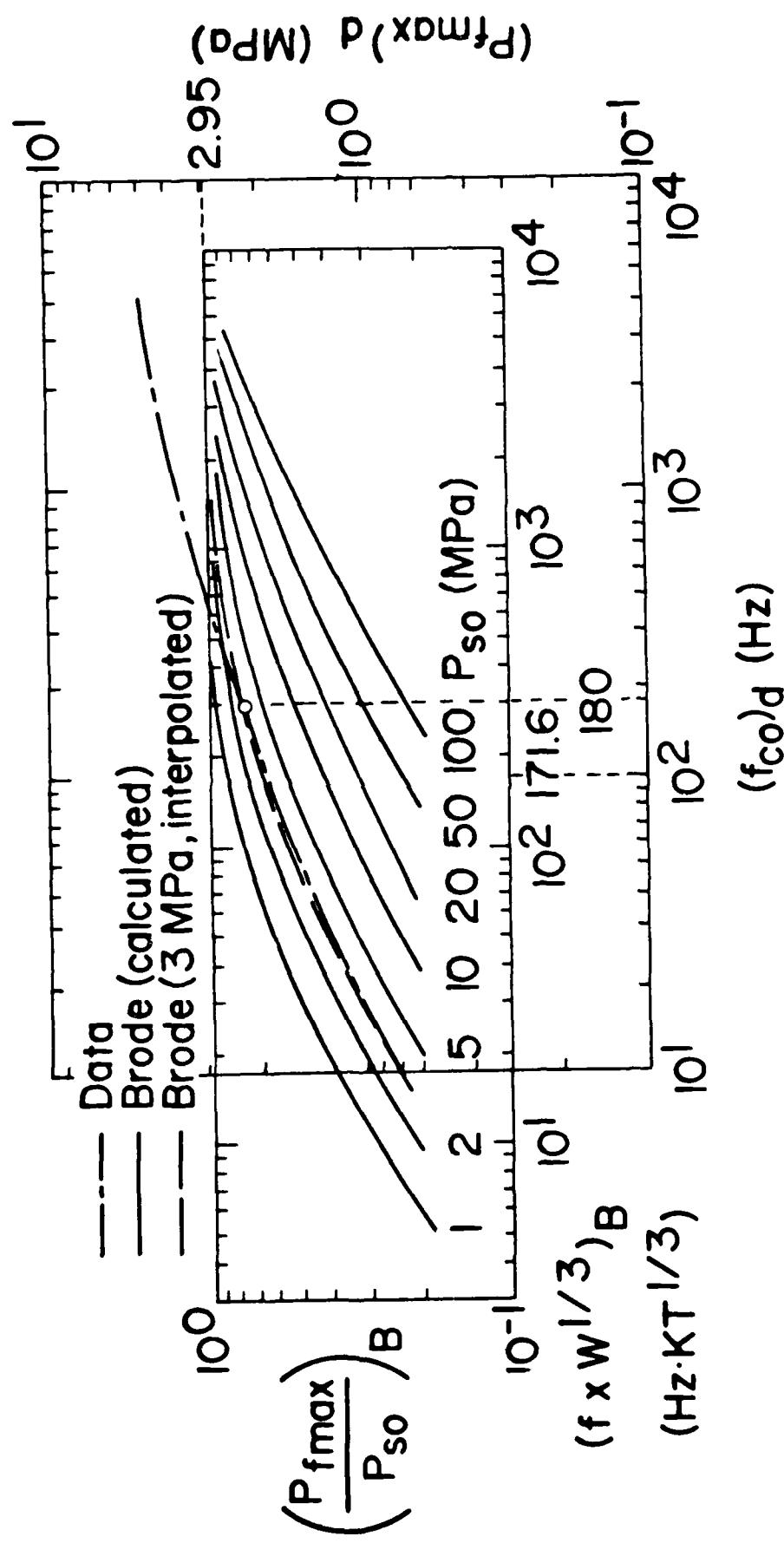


Figure 11. Overlay of typical HEST record filtered peaks compared with normalized filtered Brode peaks.

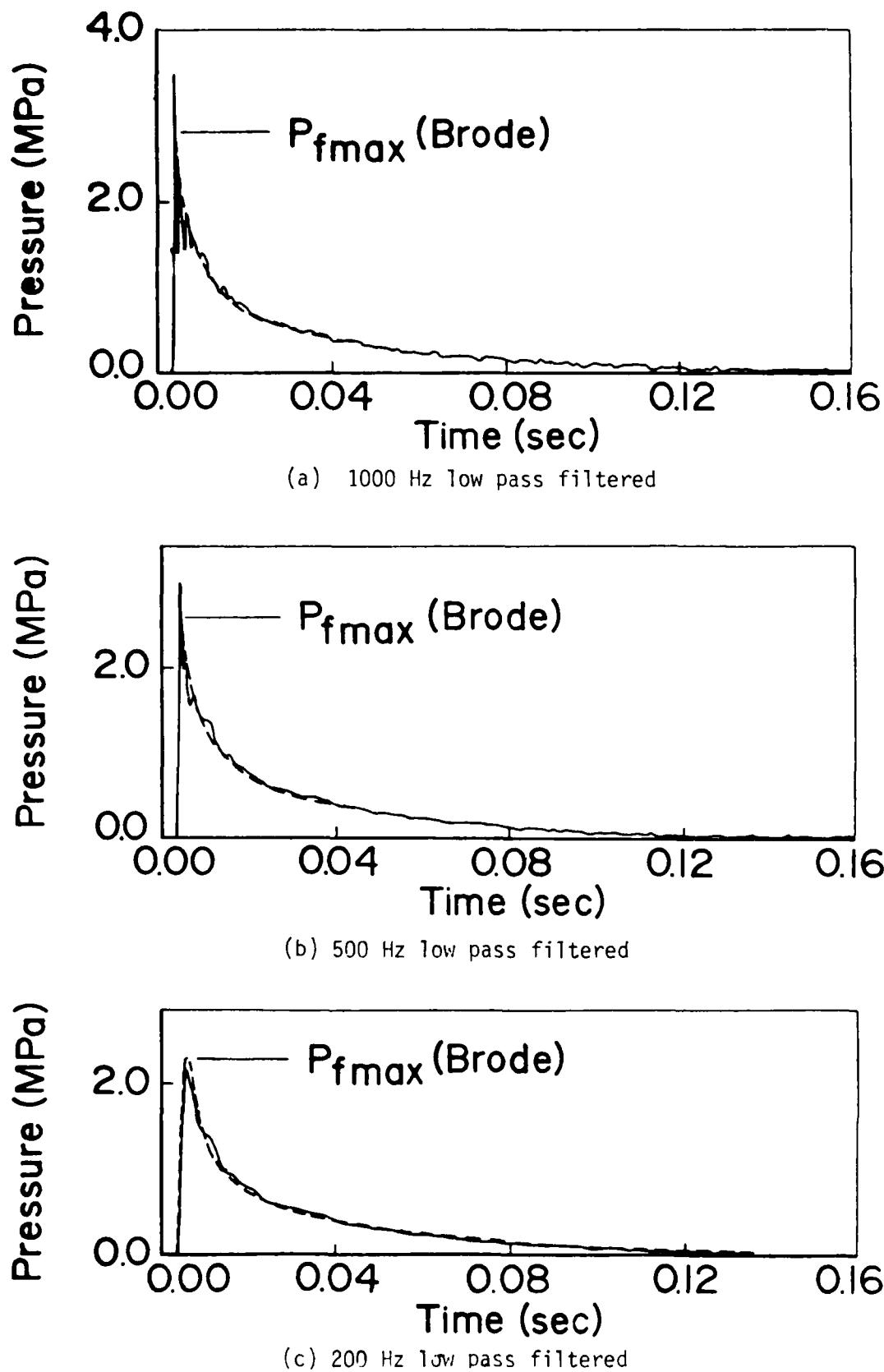


Figure 12. FOURFIT pressure history compared with example HEST record.

NORMALIZED SPEICHER-BRODE PRESSURE HISTORIES

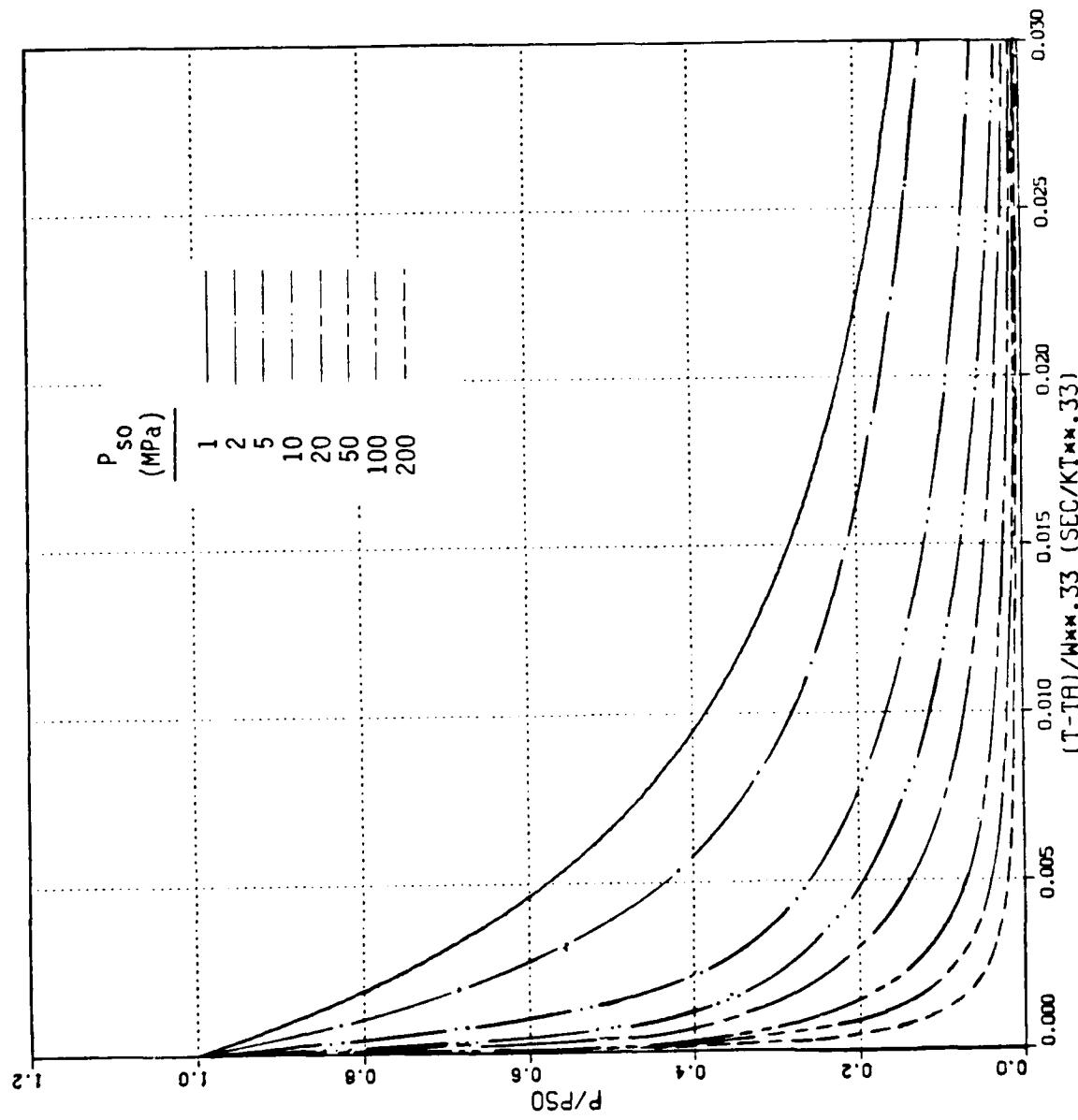


Figure 13. Normalized Speicher-Brode pressure histories.

NORMALIZED SPEICHER-BRODE IMPULSE HISTORIES

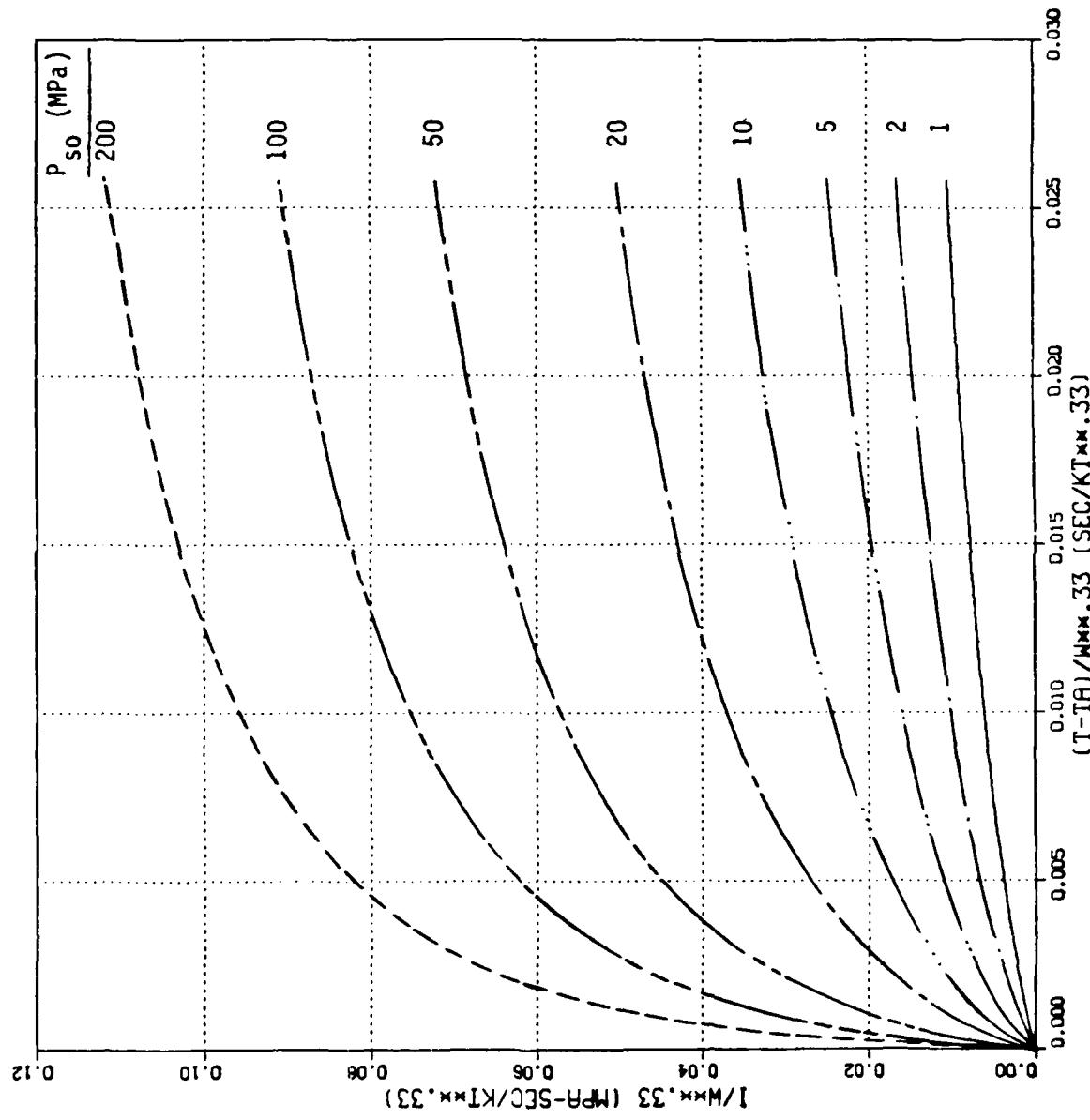


Figure 14. Normalized Speicher-Brode impulse histories.

NORMALIZED SPEICHER-BRODE FOURIER AMPLITUDE SPECTRA

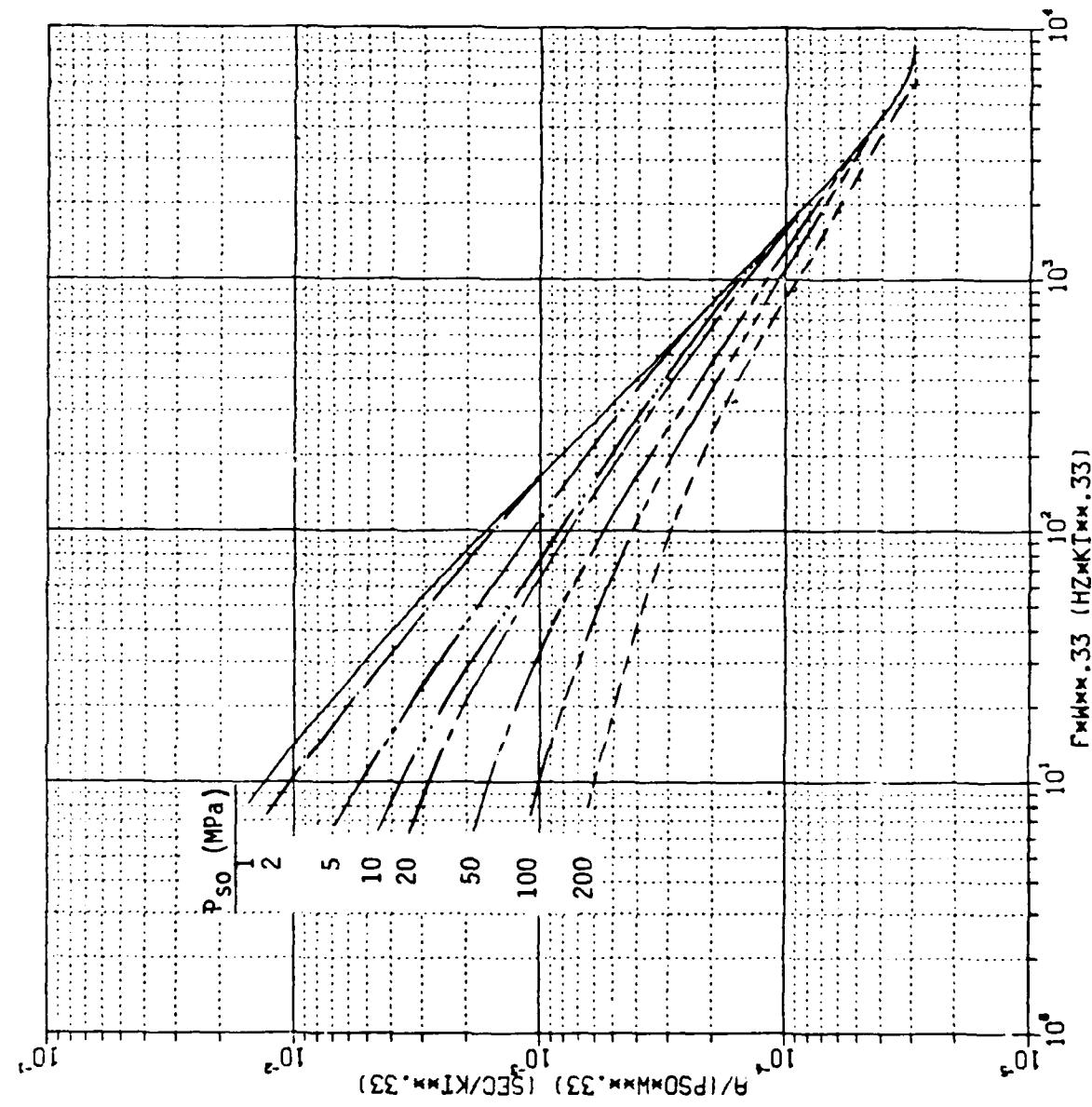


Figure 15. Normalized Speicher-Brode Fourier amplitude spectra.

```
*****  
PEAK OVERPRESSURE,MPA = .39600E+02  
NUCLEAR YIELD,KT = .87149E+00  
RANGE FROM GZ,KM = .24767E-01  
TIME OF ARRIVAL,SEC = .15382E-02  
POSITIVE PHASE DURATION,SEC = .14308E+00  
*****  
*** LOW PASS FIDELITY (HZ) = 1000. ***
```

Figure 16. Example FOURFIT output for IOPT = 1:  
automated fit to 0.35 KBAR DISC HEST record  
AB-5 (Speicher-Brode parameters listed on  
file OUTPUT).

0.35 KBAR DISC HEST AB-5

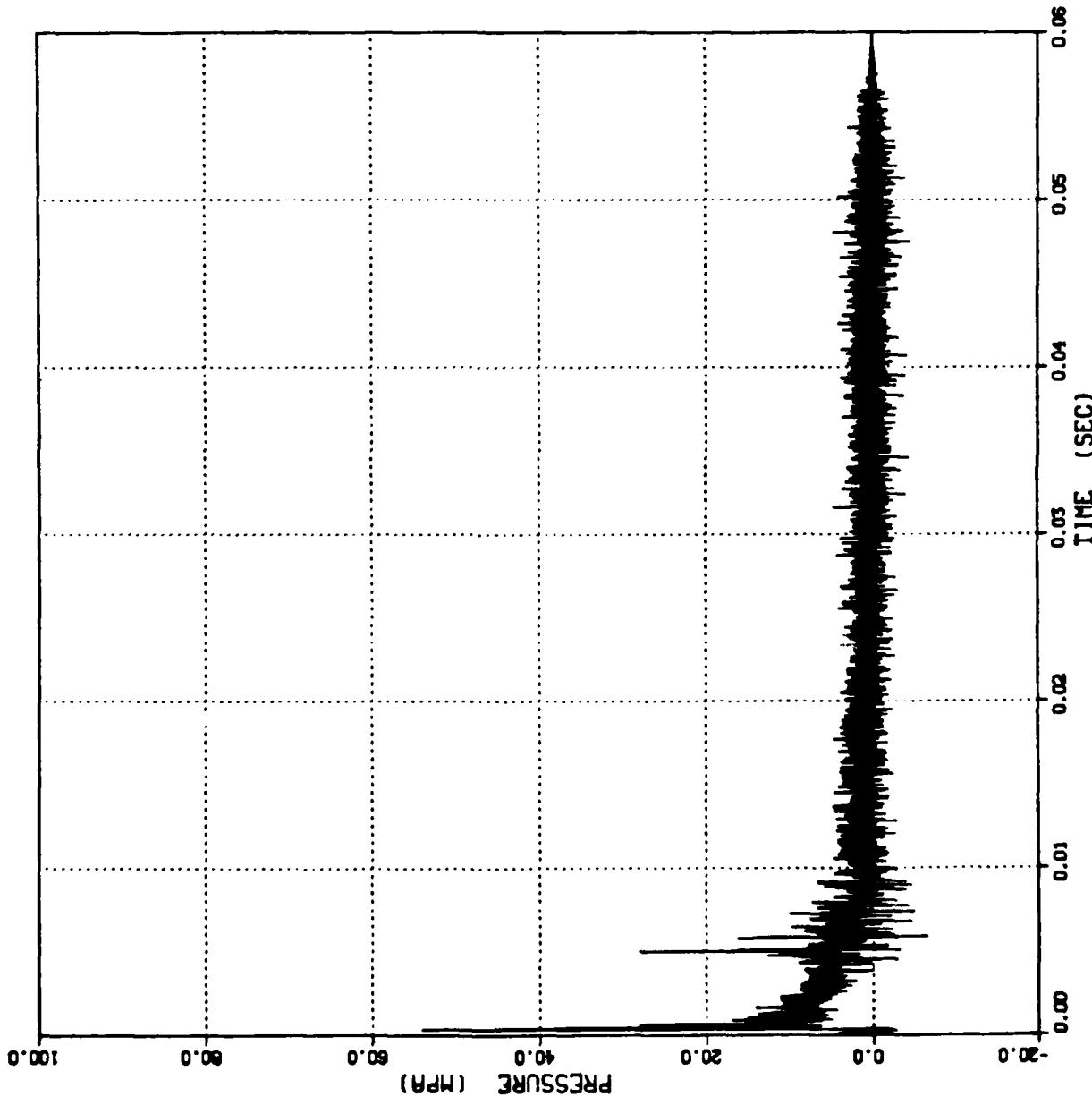


Figure 17

Example FOURFIT output  
for IOPT = 2, IFILT = -1:  
0.35 KBAR DISC HEST  
record AB-5 pressure  
history.

0.35 KBAR DISC HEST AB-5

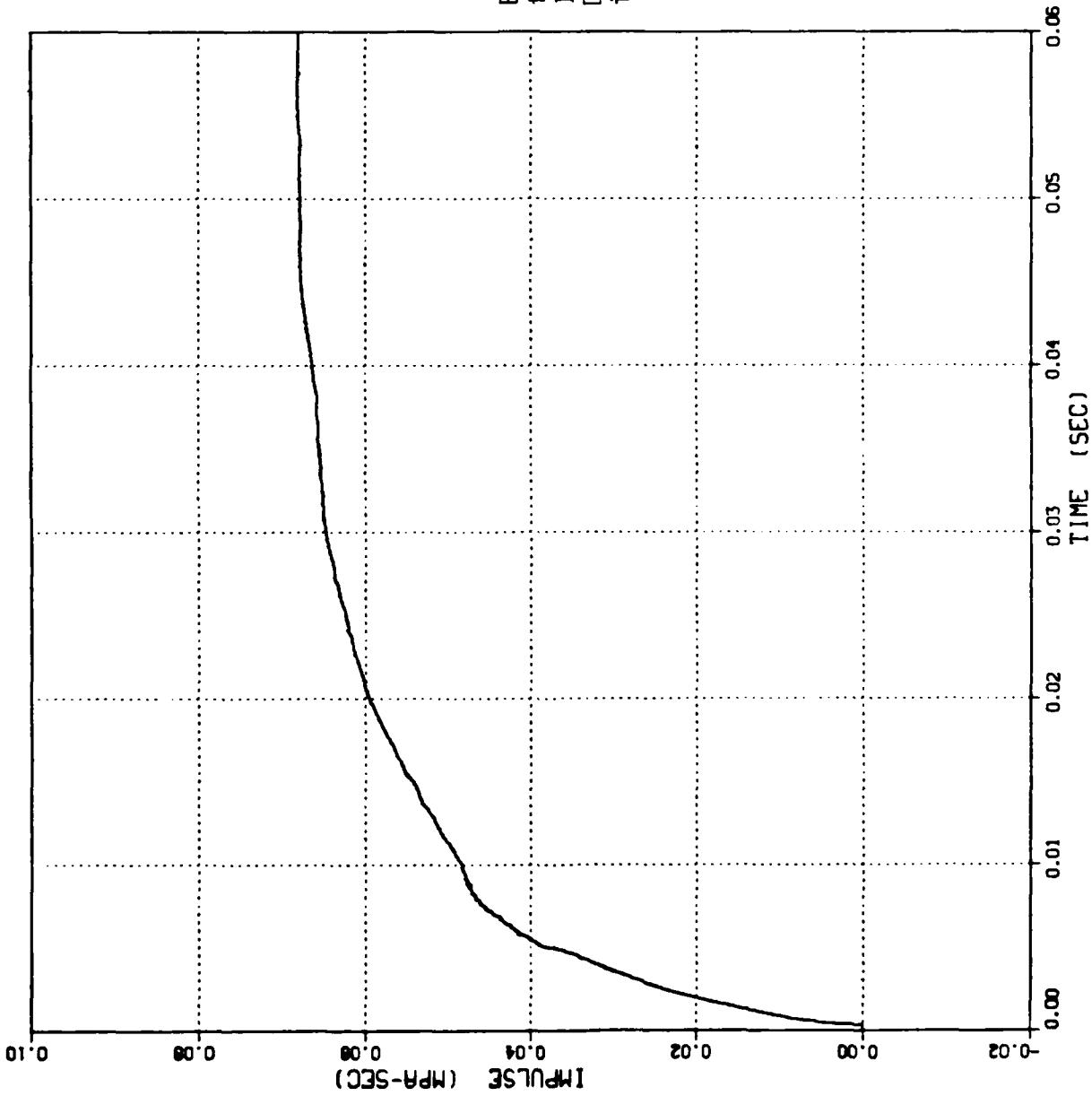
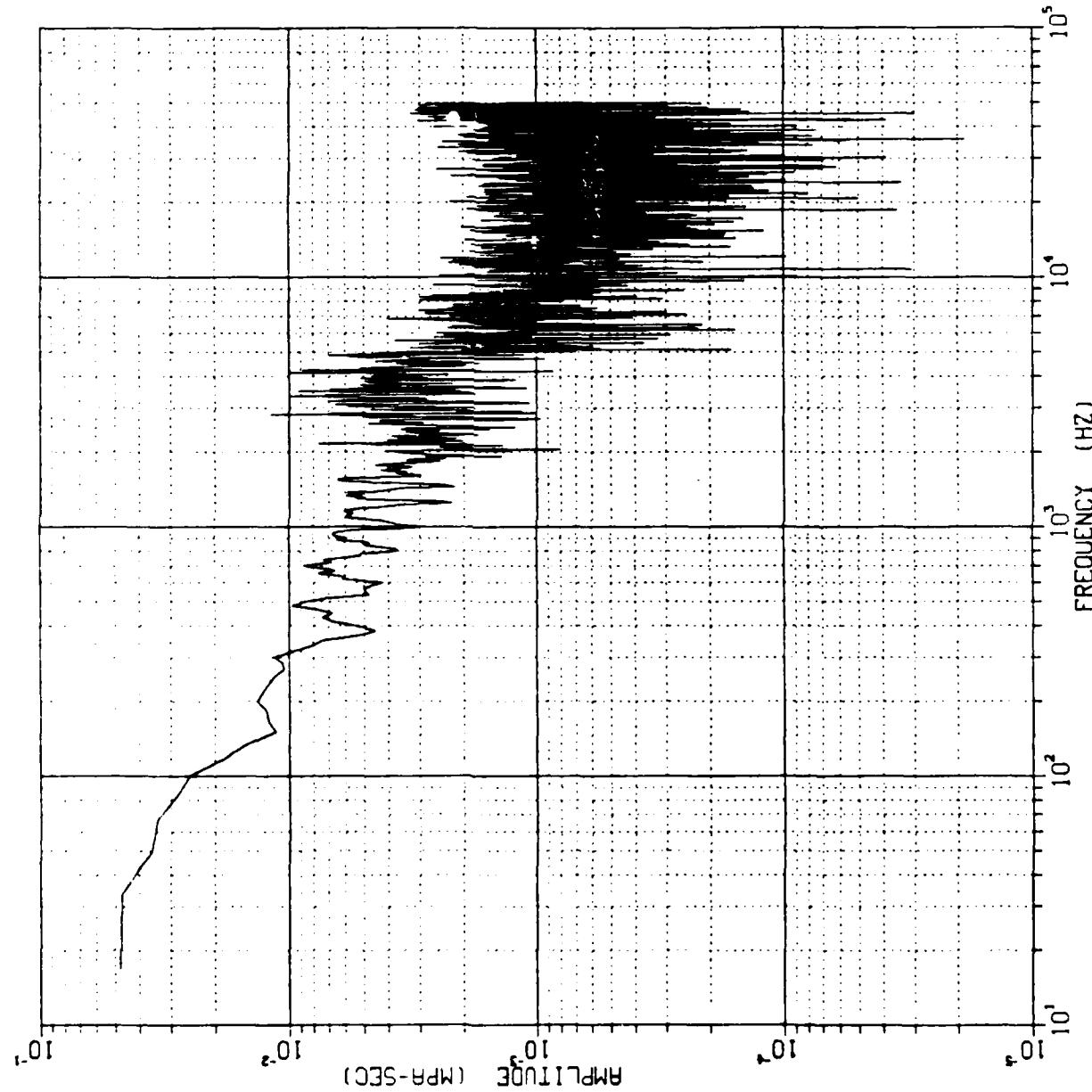


Figure 18

Example FOURFIT output  
for IOPT = 2,  
IFILT = -1: 0.35 KBAR  
DISC HEST record AB-5  
impulse history.

0.35 KBAR DISC HEST AB-5

FOURIER AMPLITUDE SPECTRUM



0.35 KBAR DISC HEST AB-5

PRESSURE HISTORY

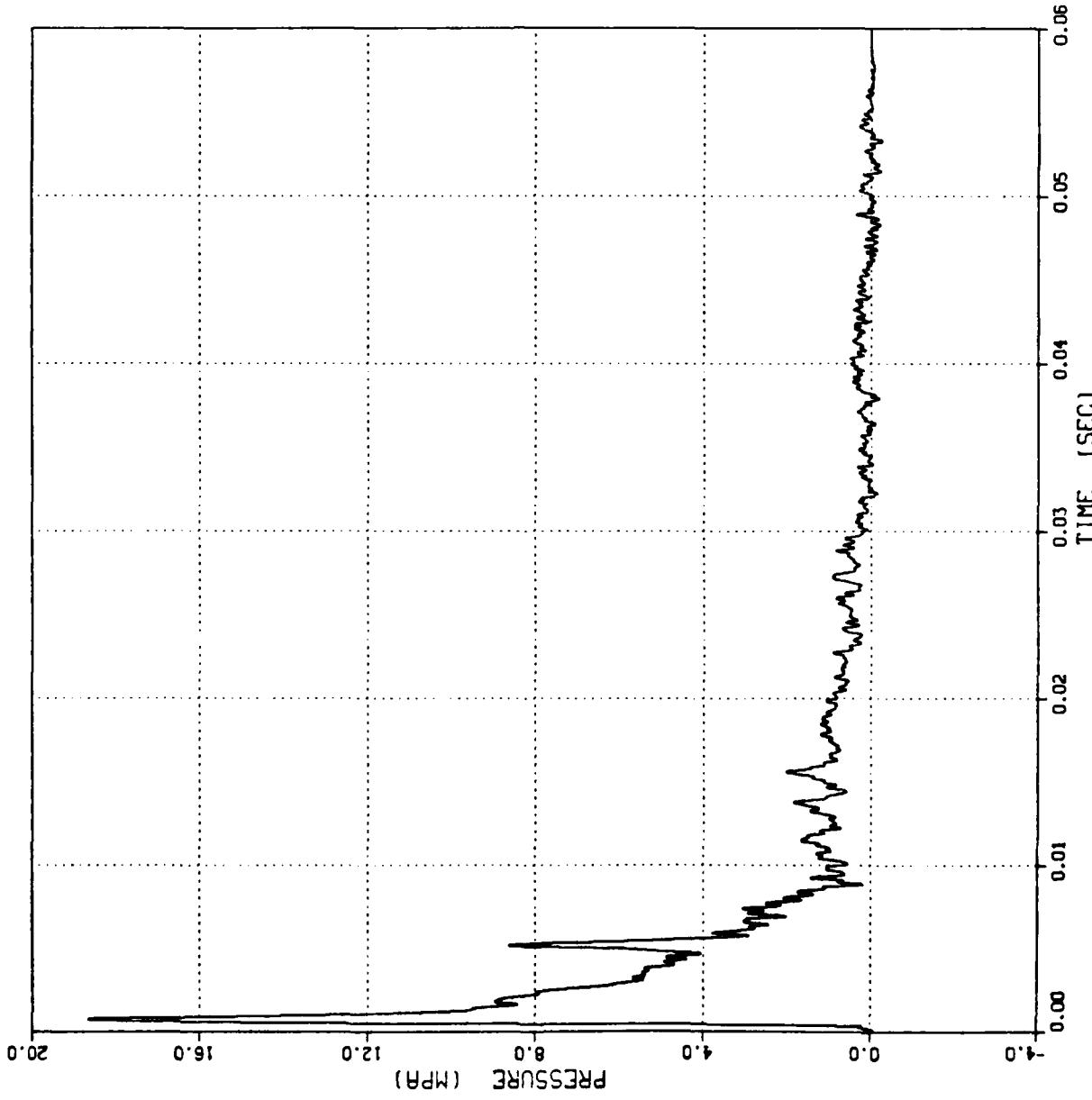


Figure 20

Example FOURFIT output for  
IOPT = 2, IFILT = 1,  
FL0 = 1000.: 0.35 KBAR DISC  
HEST record AB-5 low pass  
filtered pressure history.

### CALCULATED SPEICHER-BRODE PRESSURE HISTORY

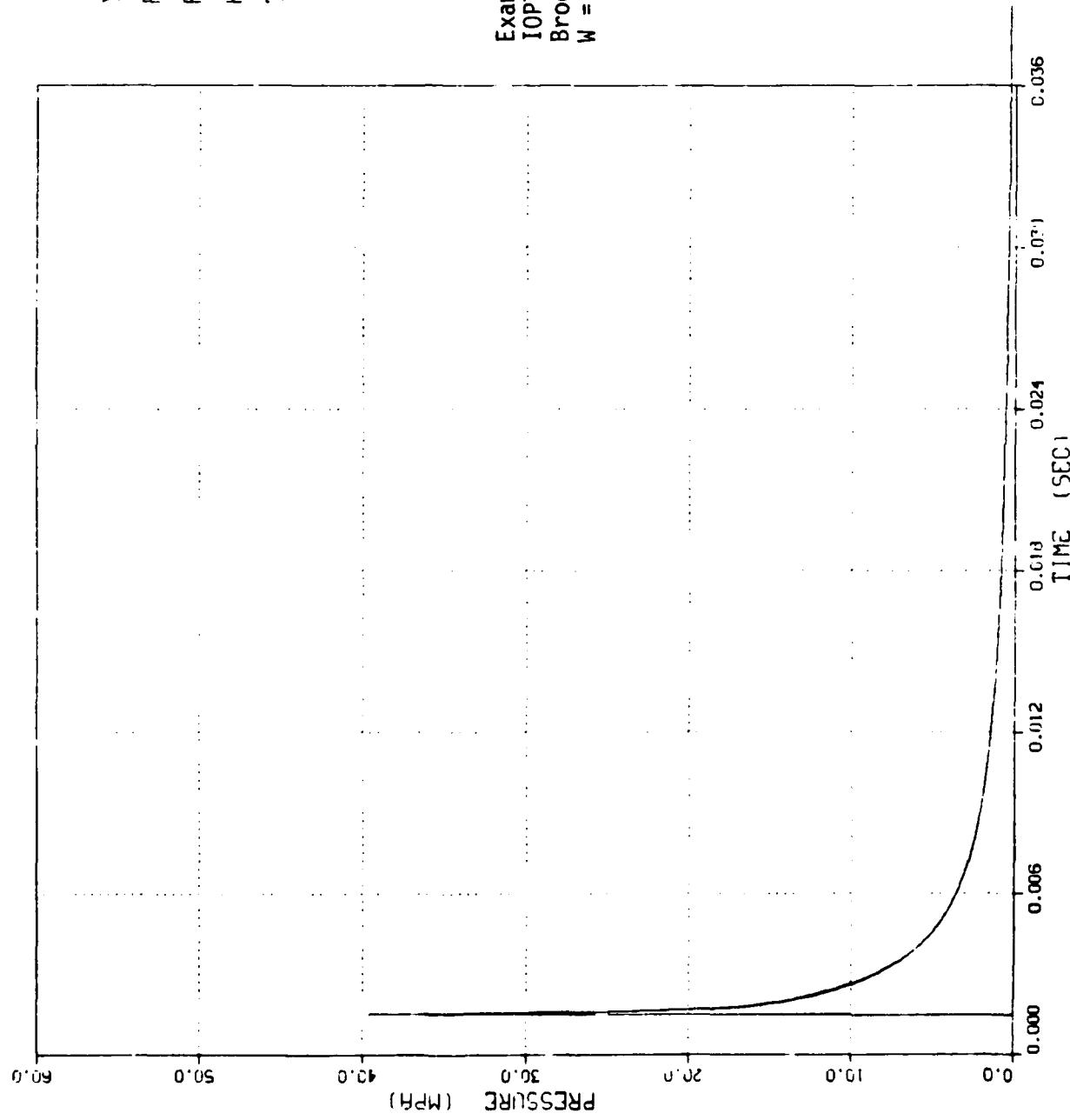


Figure 21

Example FOURFIT output for  
IOPT = 3, IFILT = -1: Speicher-  
Brode ( $P_{so} = 39.60$  MPa,  
 $W = 0.87$  KT) pressure history.

CALCULATED SPEICHER-BRODE IMPULSE HISTORY

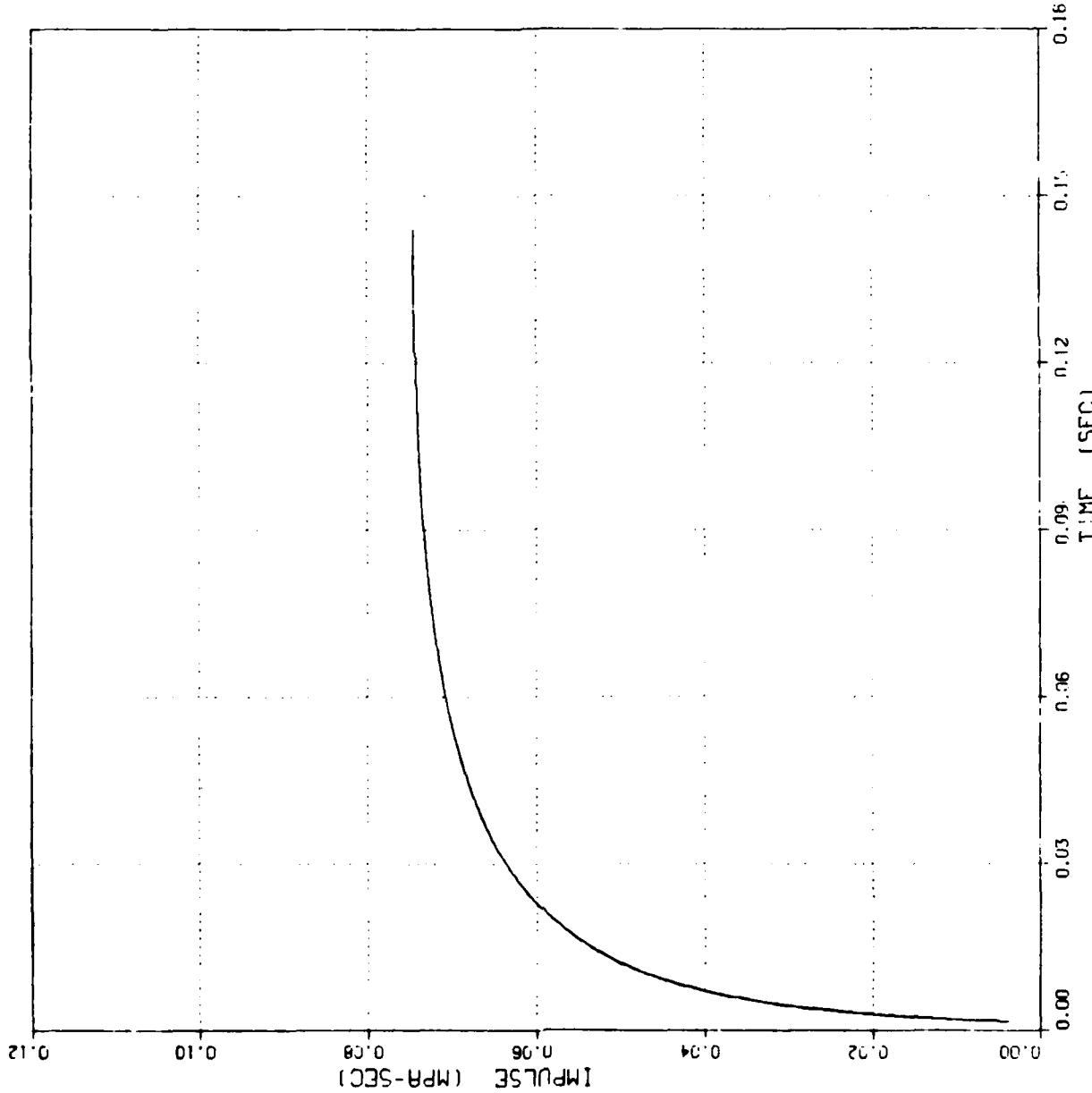
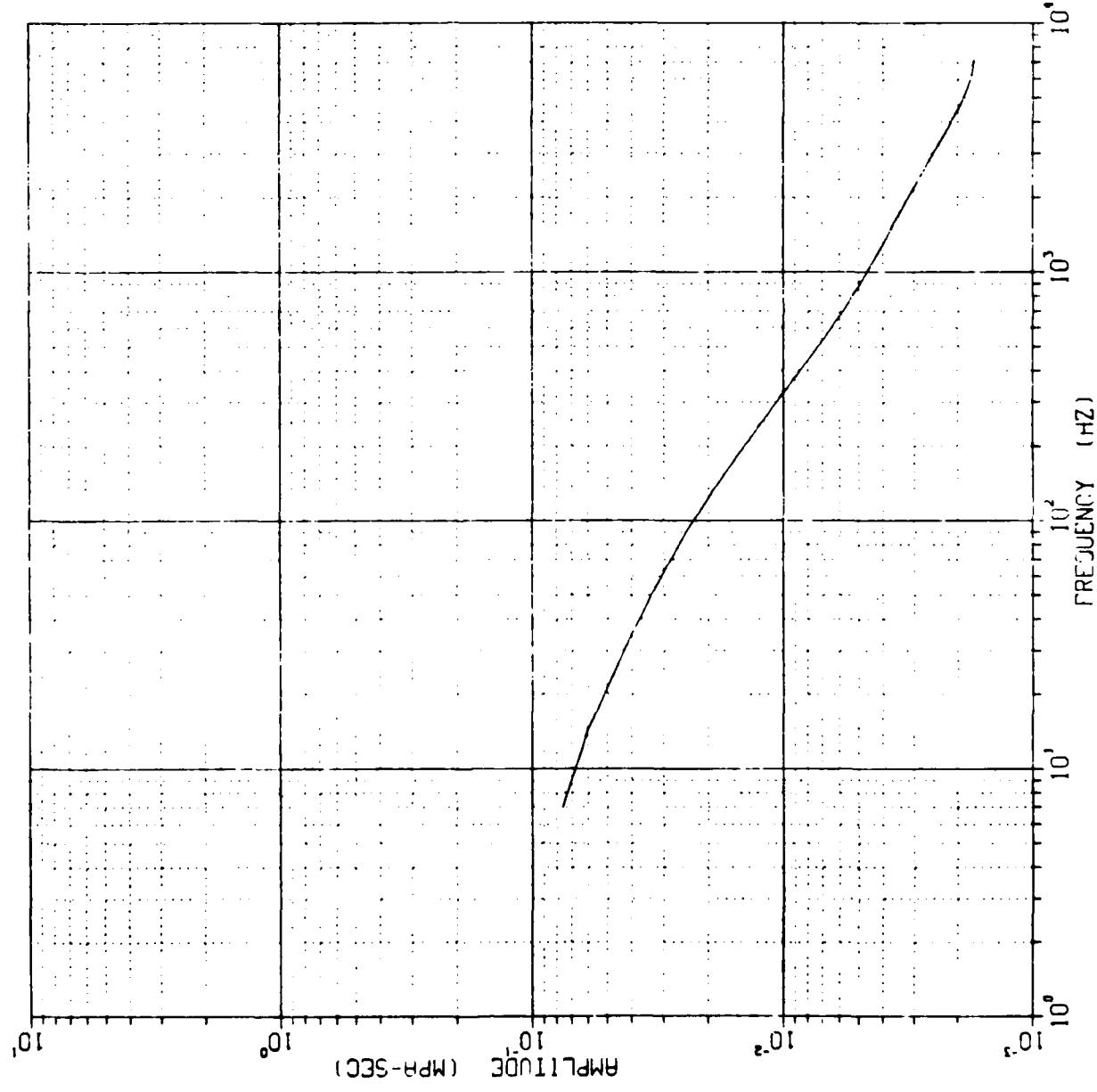


Figure 22

Example FOURFIT output for  
10PT = 3, 1FLT = -1;  
Speicher-Brode ( $P_{SO} = 39.60$  MPa,  $W = 0.87$  KT)  
impulse history.

CALCULATED SPEICHER-BRODE FOURIER AMPLITUDE SPECTRUM



YIELD (KT) -	0.87
P <sub>so</sub> (MPA) -	39.60
RANGE (KM) -	0.02475
POS. PHASE (SEC) -	0.14297
TOA (SEC) -	0.000153

CALCULATED SPEICHER-BRODE PRESSURE HISTORY

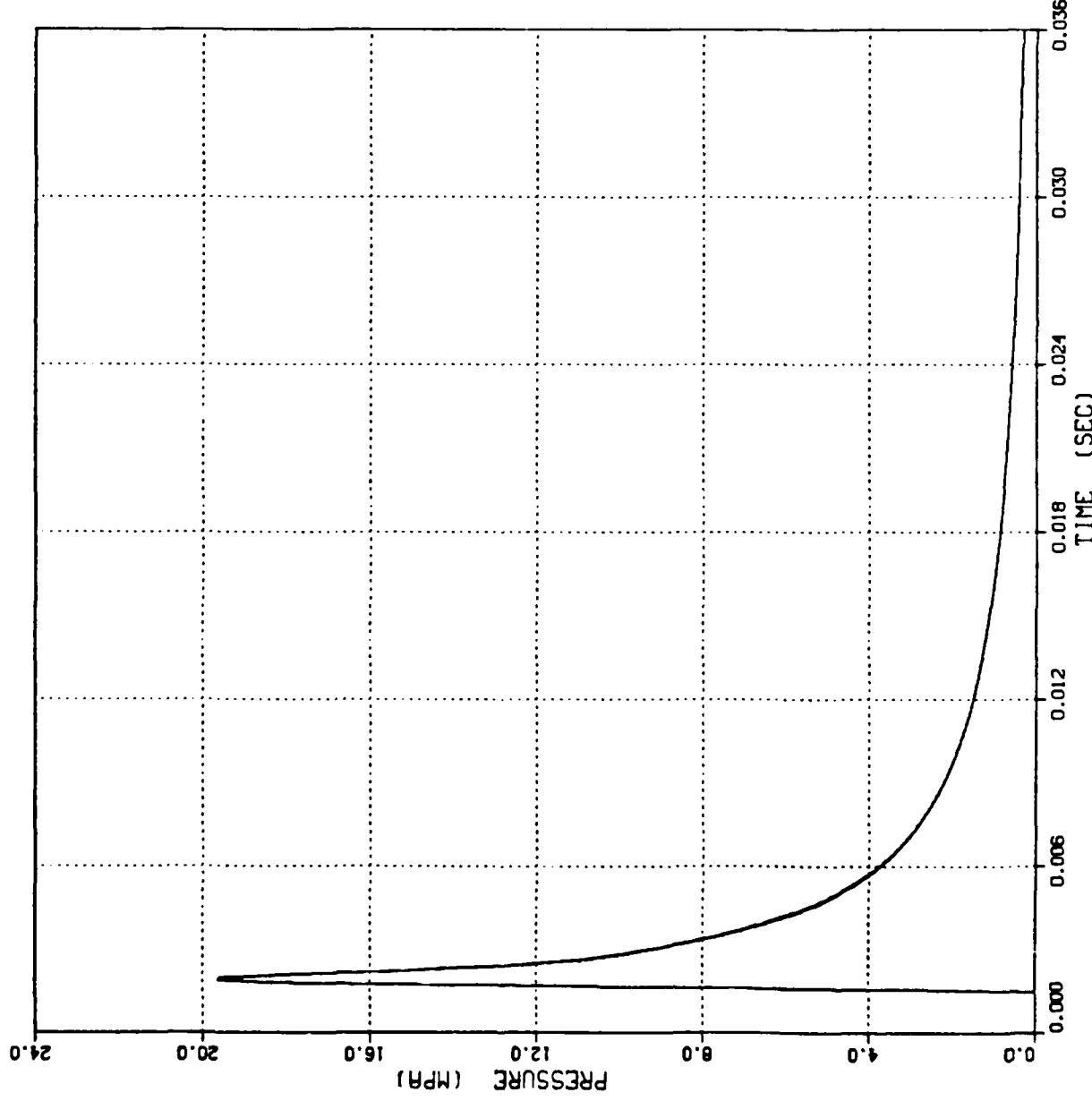


Figure 24

Example FOURFIT output for  
 10PT = 3, IFILT = 1, FL0 = 1000. :  
 Speicher-Brode ( $P_{so} = 39.60$  MPa,  
 $W = 0.87$  KT) low pass filtered  
 pressure history.

LOW PASS FILTER  
 FCUTOFF (HZ) = 1000.

0.35 KBAR DISC HEST AB-5  
WITH FOURFIT SPEICHER-BRONE

PRESSURE HISTORY

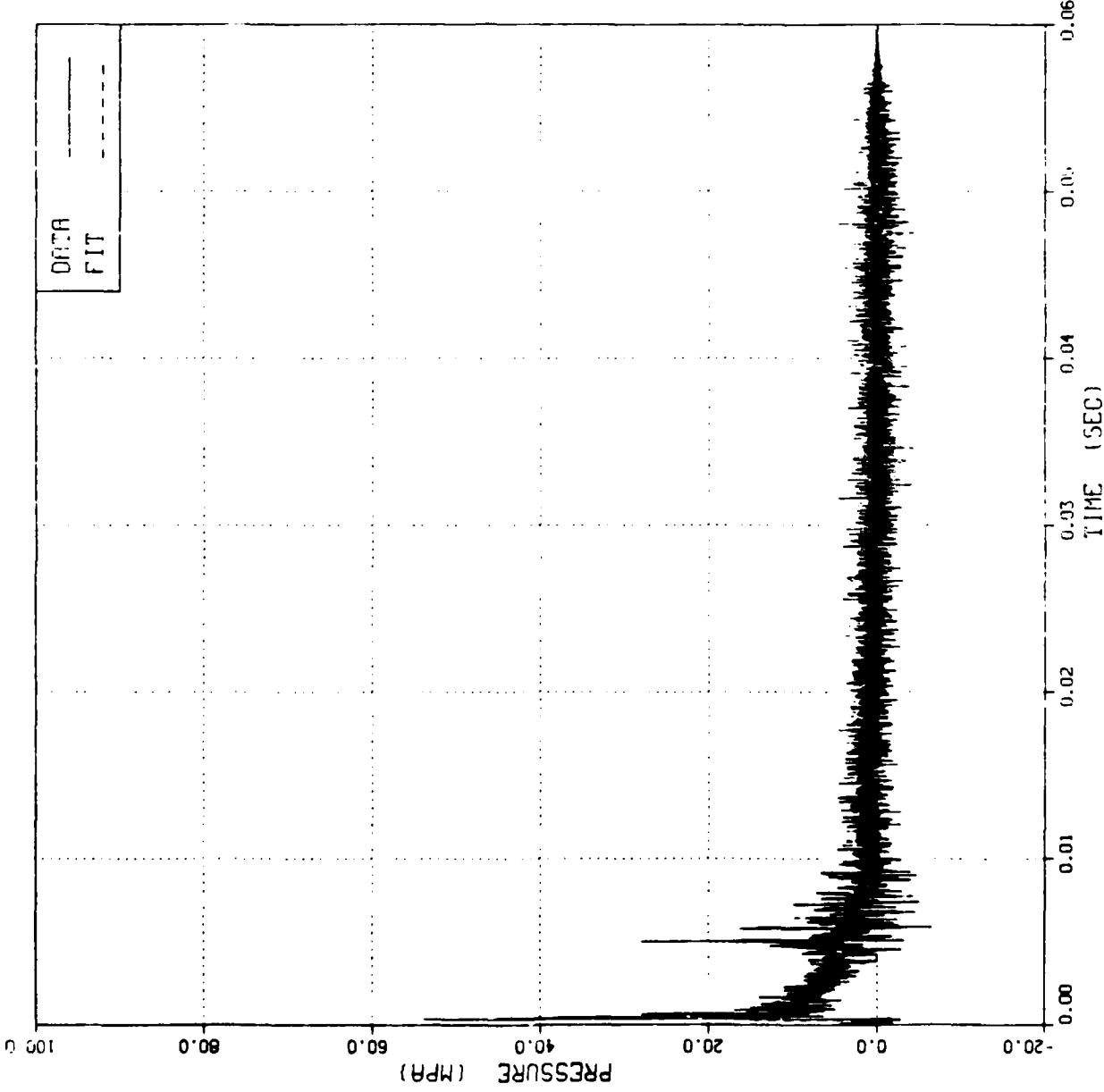


Figure 25

Example FOURFIT output for  
IOPF = 1: automated fit to  
0.35 KBAR DISC HEST record AB-5  
pressure history comparison.

0.35 KBAR DISC HEST AB-5  
WITH FOURFIT SPEICHER-BRODE

IMPULSE HISTORY

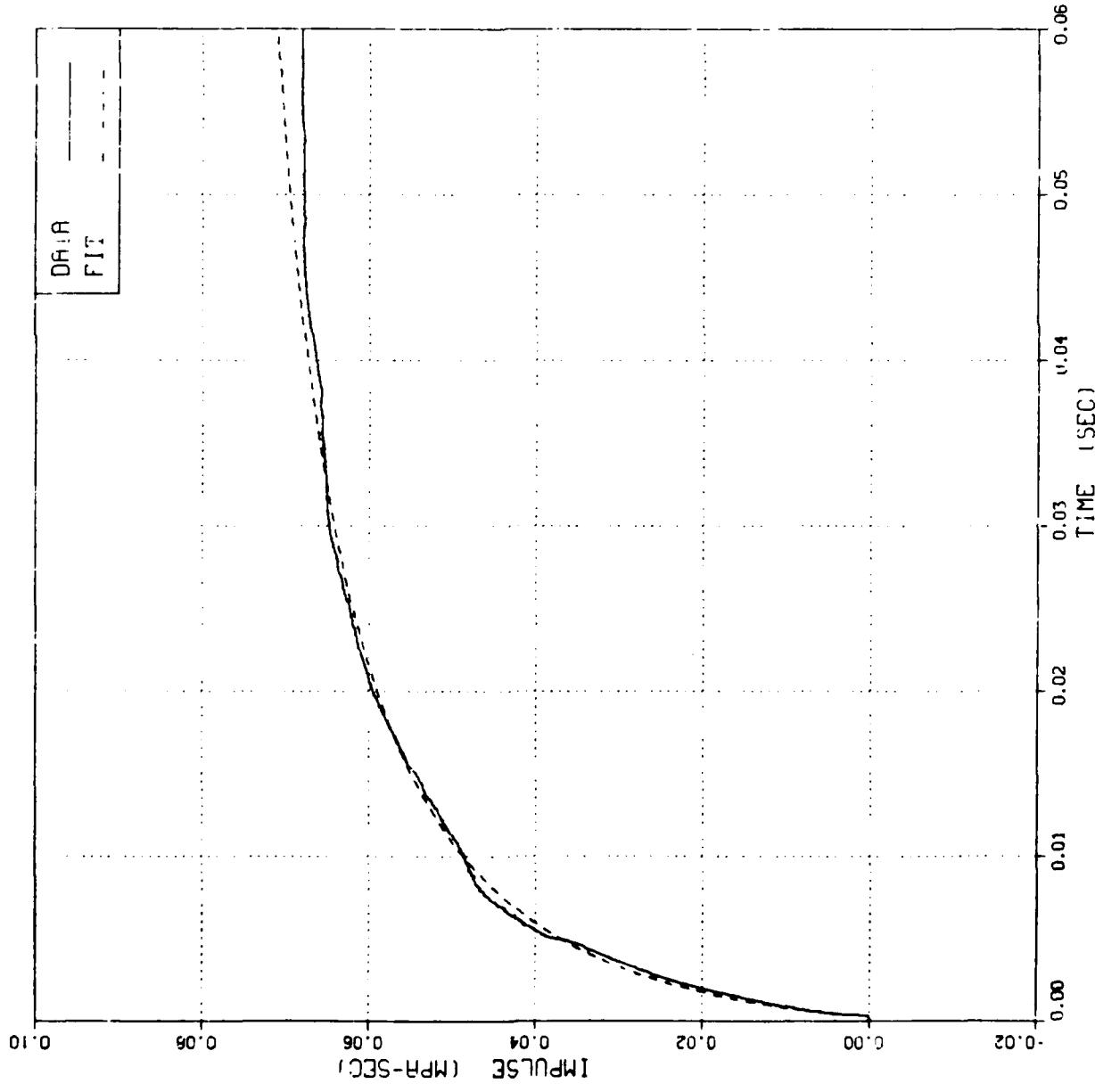
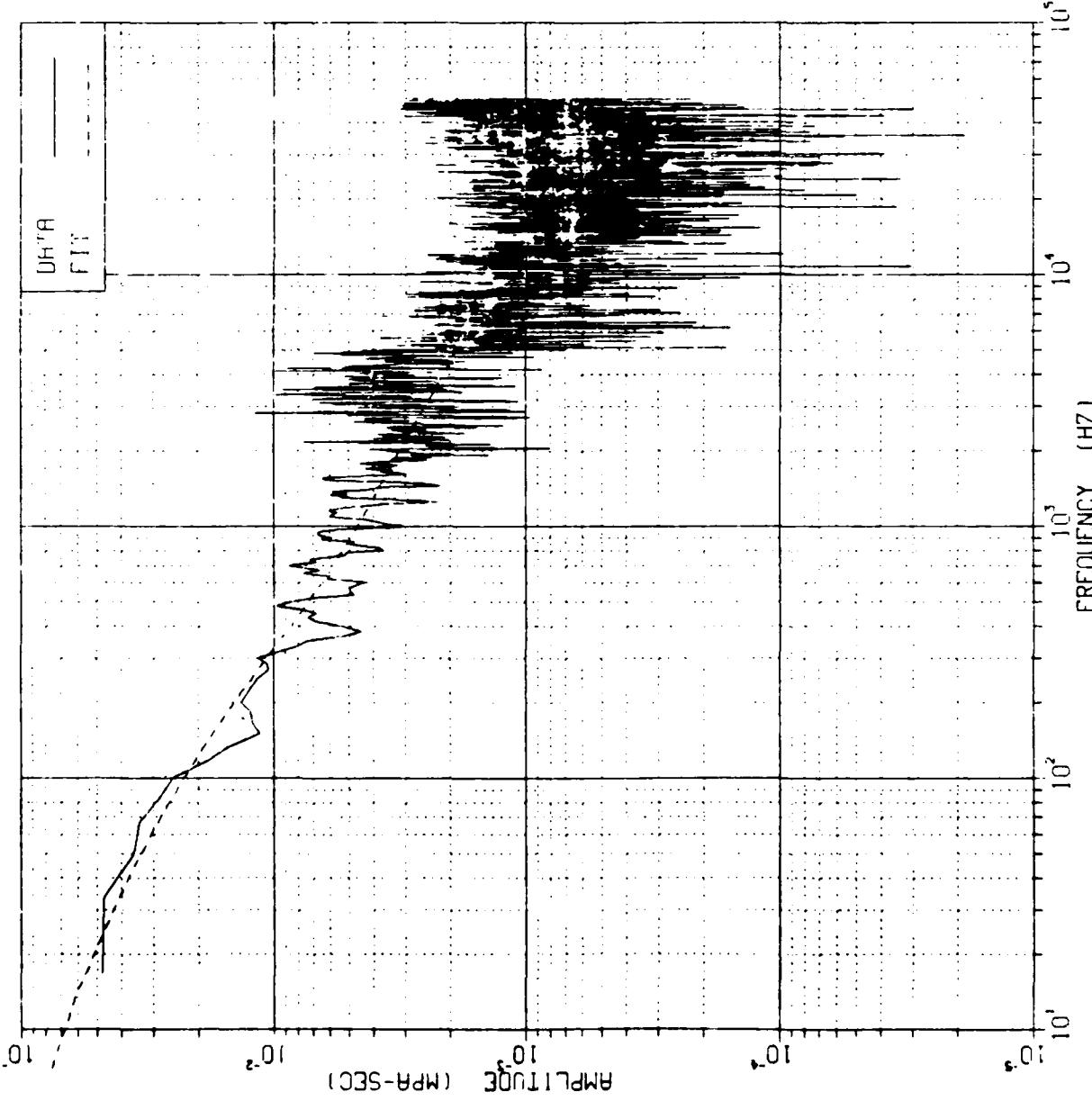


Figure 26

Example FOURFIT output for  
IOPT = 1: automated fit to  
0.35 KBAR DISC HEST record AB-5  
impulse history comparison.

0.35 KBAR DISC HEST AB 5  
WITH FOURFIT SPEICHER-ERODE

FOURIER AMPLITUDE SPECTRUM



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YIELD (kT) -	0.87
PSG (MPA) -	39.60
RFAGE (KM) -	0.02477
POS. PHASE (SEC) -	0.14308
TOA (SEC) -	0.000154
LOW PASS FID (HZ) -	1000.

Figure 27

Example FOURFIT output for  
IOPT = 1: automated fit to  
0.35 KBAR DISC HEST record AB-5  
Fourier amplitude spectrum  
comparison.

0.35 KBAR DISC HEST AB-5  
WITH FOURFIT SPEICHER-BRODE

PRESSURE HISTORY

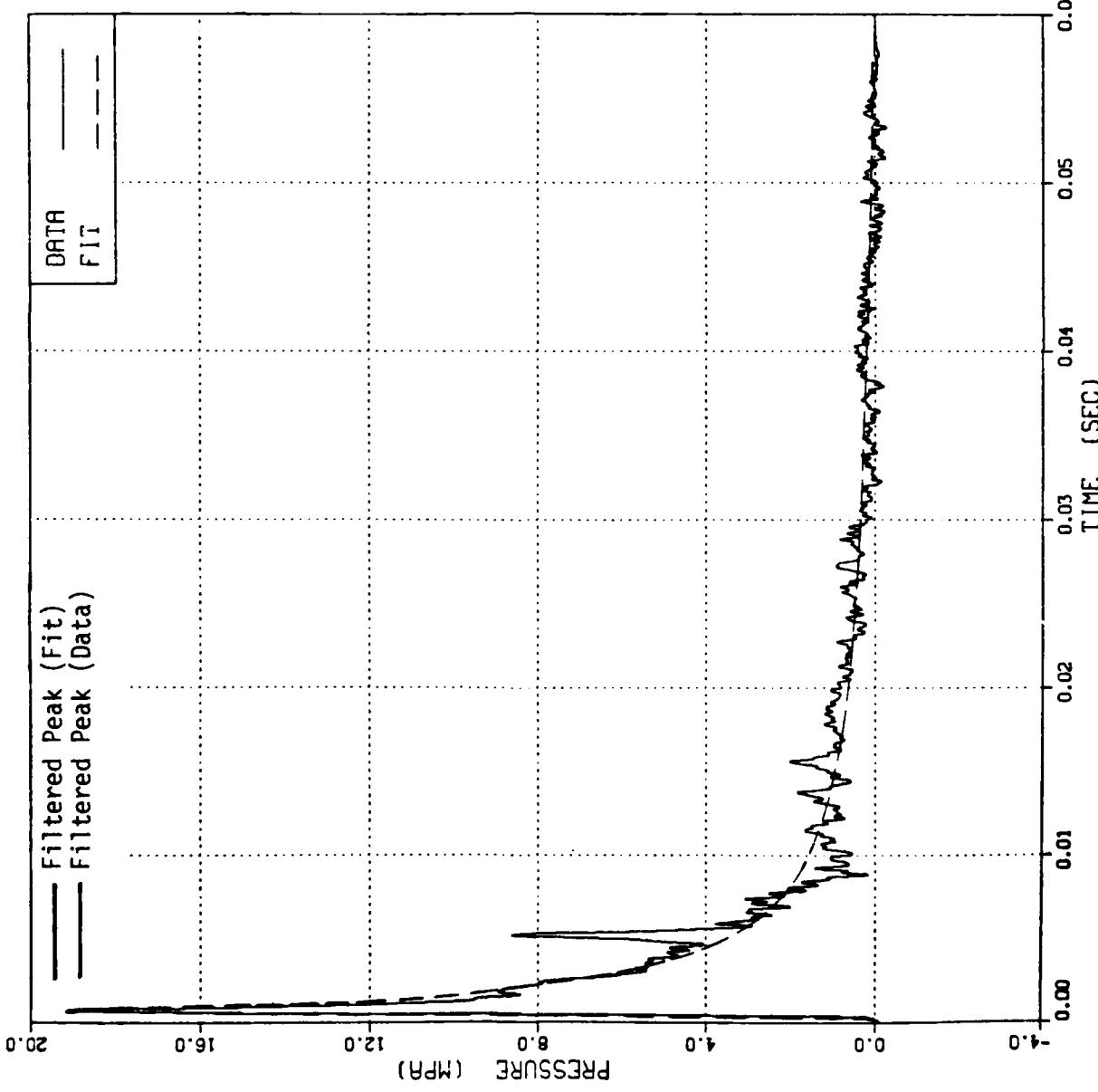


Figure 28

0.35 KBAR DISC HEST record AB-5  
and FOURFIT automated fit:  
fidelity frequency low pass  
filter comparison.

0.35 KBAR DISC HEST AB-3  
WITH FOURFIT SPEICHER-ERODE.

PRESSURE HISTORY

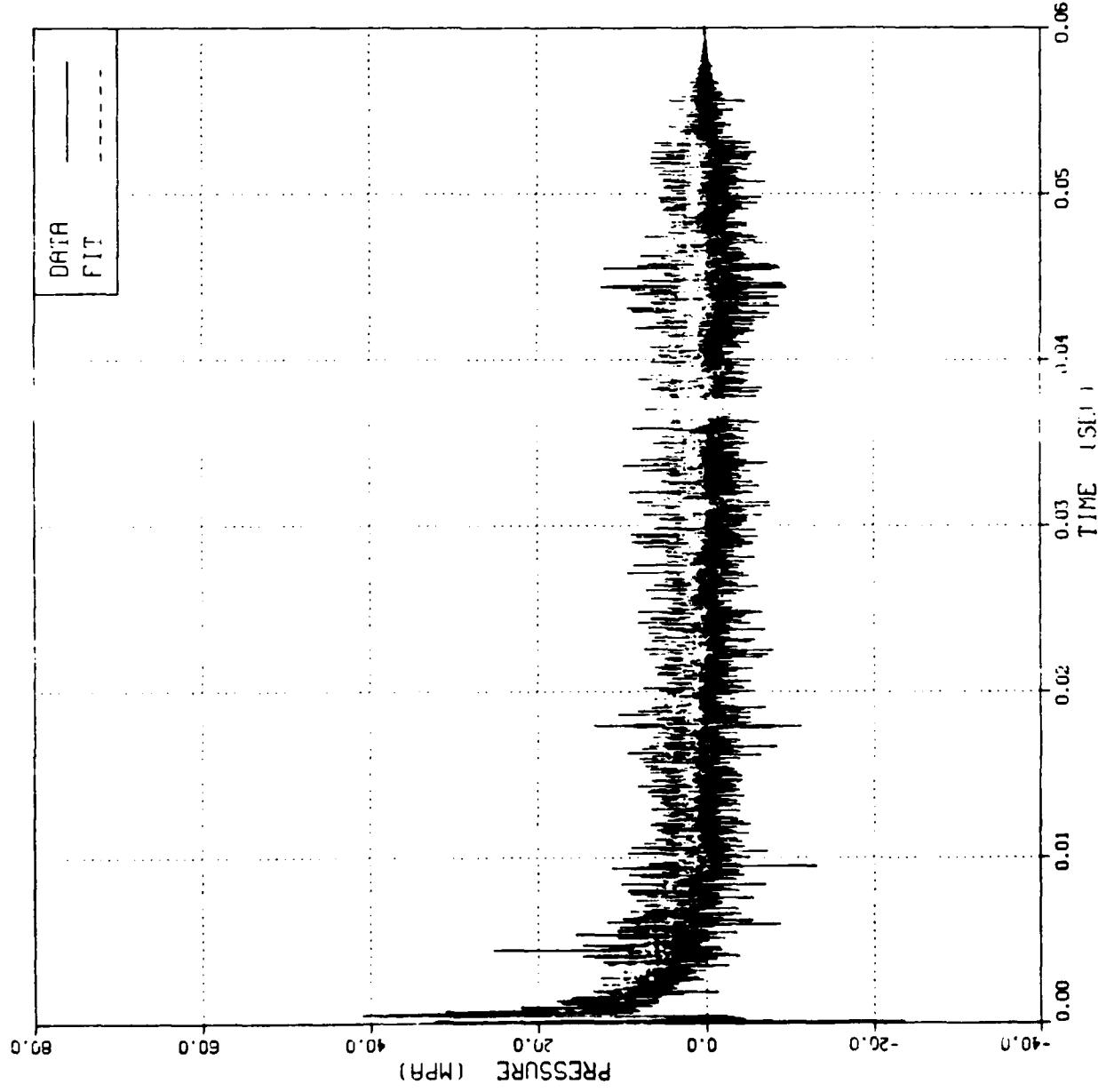


Figure 29

FOURFIT automated fit to 0.35  
KBAR DISC HEST record AB-3:  
pressure history comparison.

0.35 KBAR DISC HEST AB-3  
WITH FOURFIT SPEICHER-BRODE

IMPULSE HISTORY

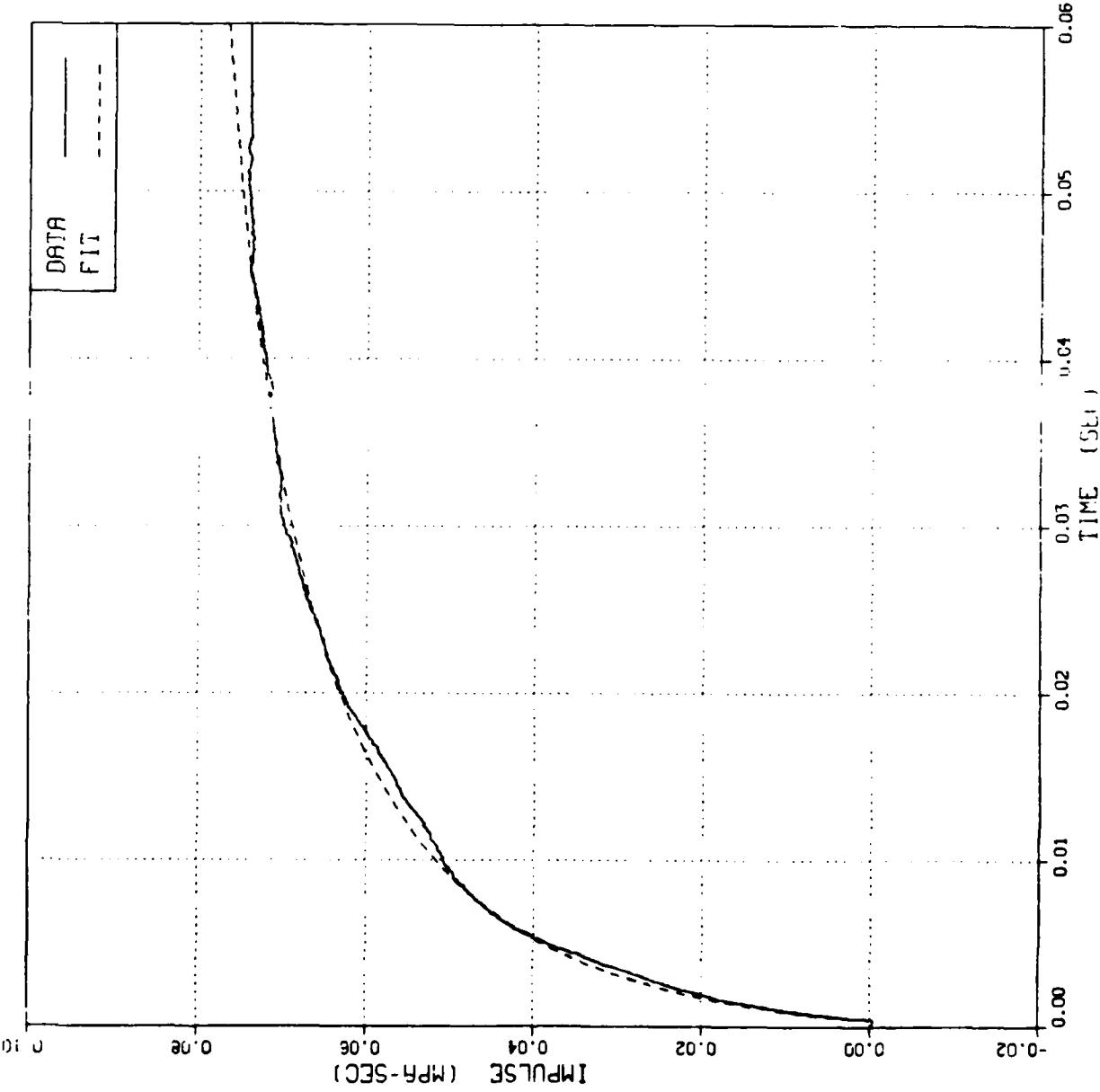
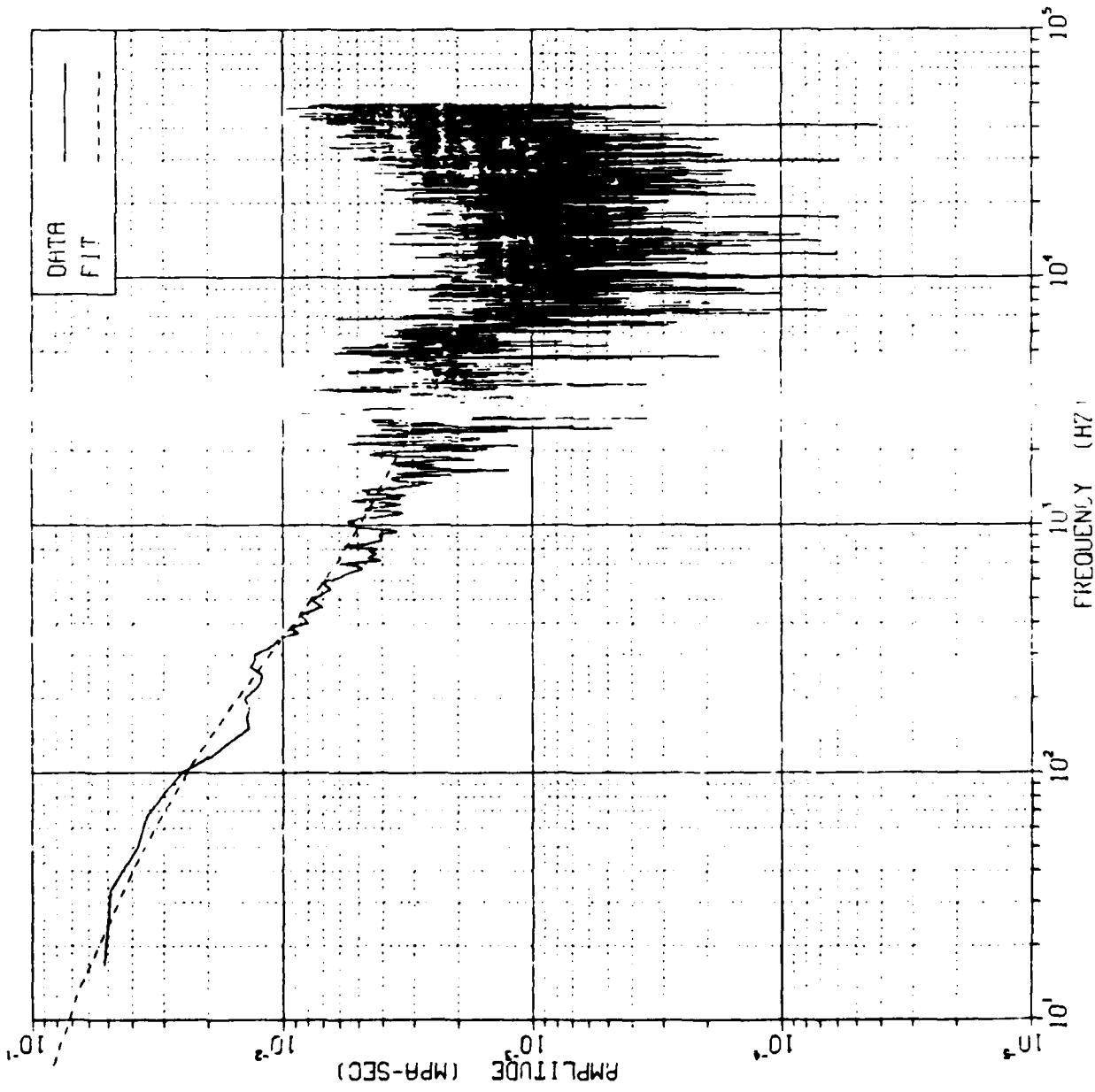


Figure 30

FOURFIT automated fit to  
0.35 KBAR DISC HEST record  
AB-3: impulse history  
comparison.

0.35 KBAR DISC HEST AB-3  
WITH FOURFIT SPEICHER-BRODE

FOURIER AMPLITUDE SPECTRUM



YIELD (KT) -	1.07
PSO (MPA) -	41.45
RANGE (KM) -	0.02608
POS. PHASE (SEC) -	0.15250
TOA (SEC) -	0.00158
LOW PASS FID (HZ) -	5000.

Figure 31

FOURFIT automated fit to  
0.35 KBAR DISC HEST record  
AB-3: Fourier amplitude  
spectrum comparison.

0.35 KBAR DISC HEST AB 4  
WITH FOURFIT SPEICHER-BRODE

PRESSURE HISTORY

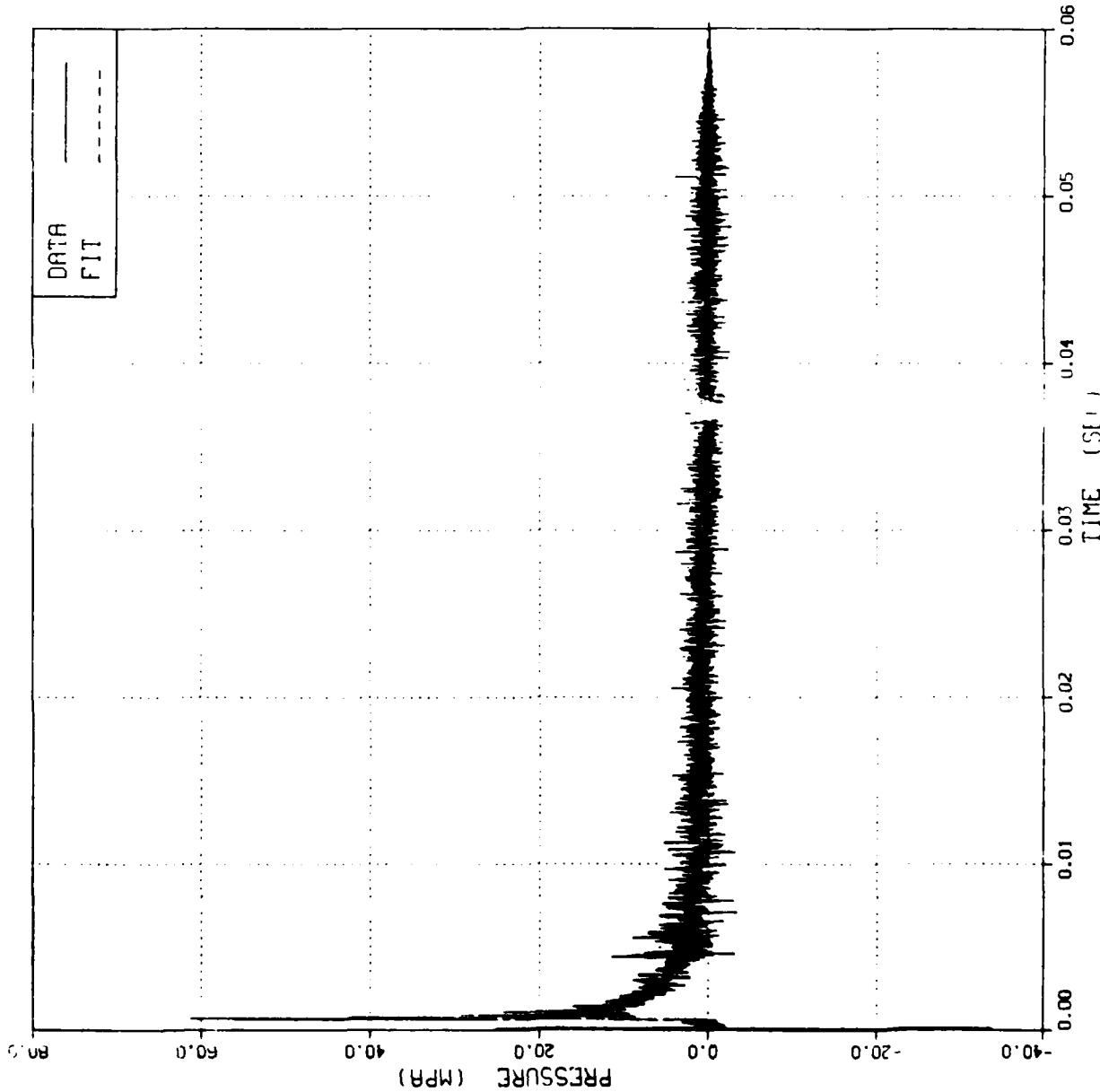
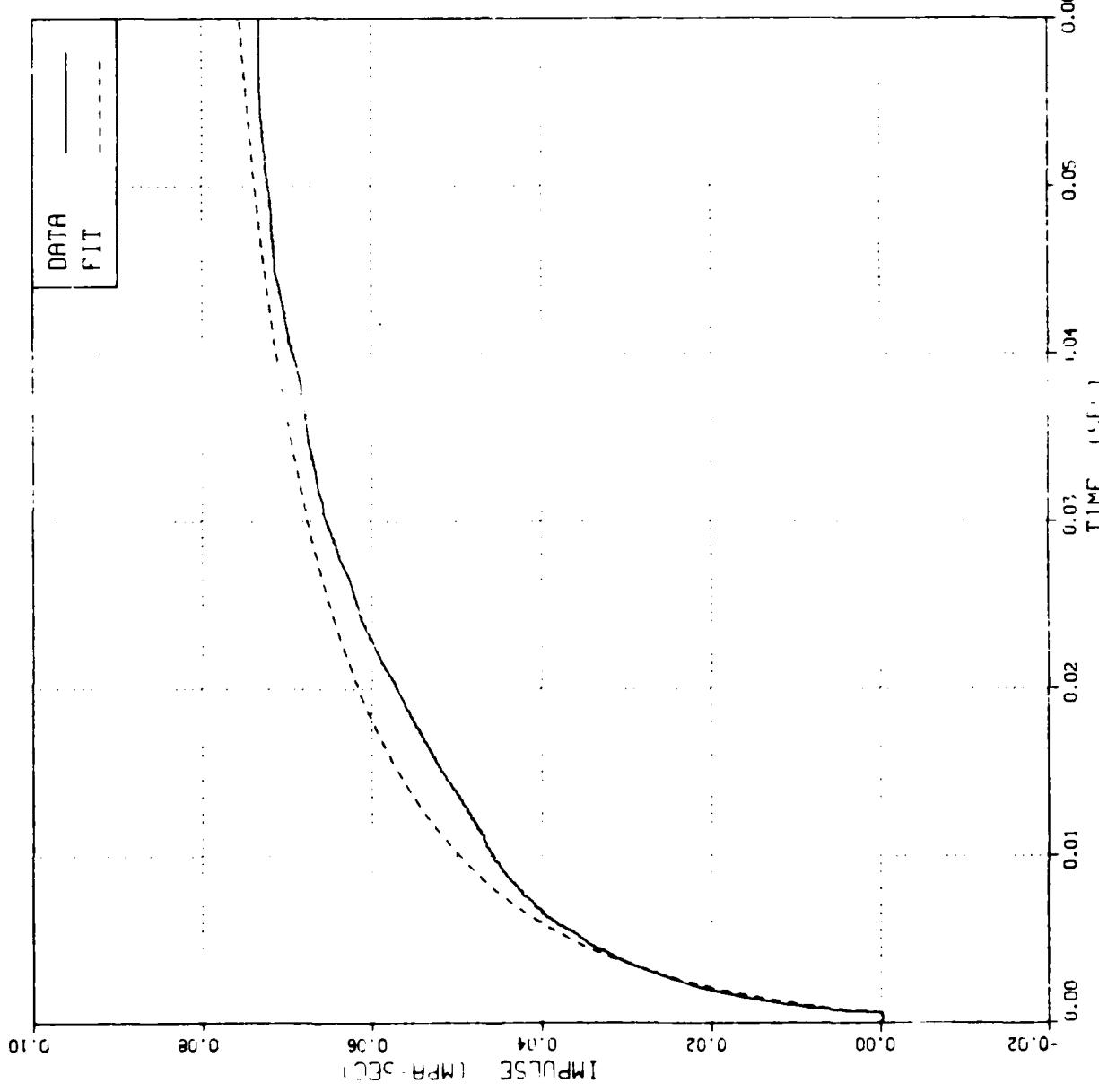


Figure 32

FOURFIT automated fit to  
0.35 KBAR DISC HEST record  
AB-4: pressure history  
comparison.

0.35 KBAR DISC HEST AB-4  
WITH FOURFIT SPEICHER-BRODE.

IMPULSE HISTORY



0.35 KBAR DISC HEAT AB-4  
WITH FOURFIT SPEICHER-PROBE

FOURFIT AMPLITUDE SPECTRUM

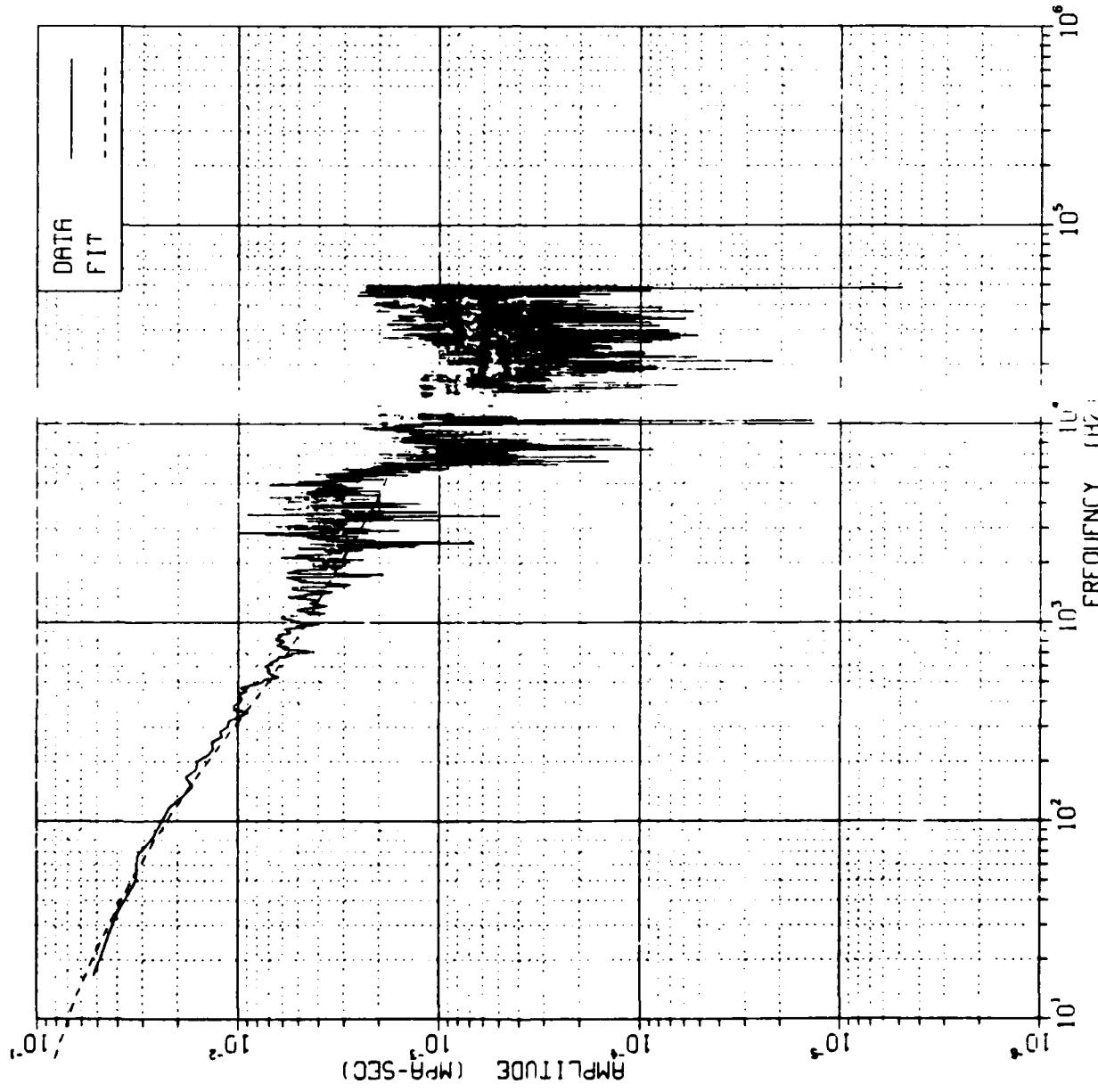
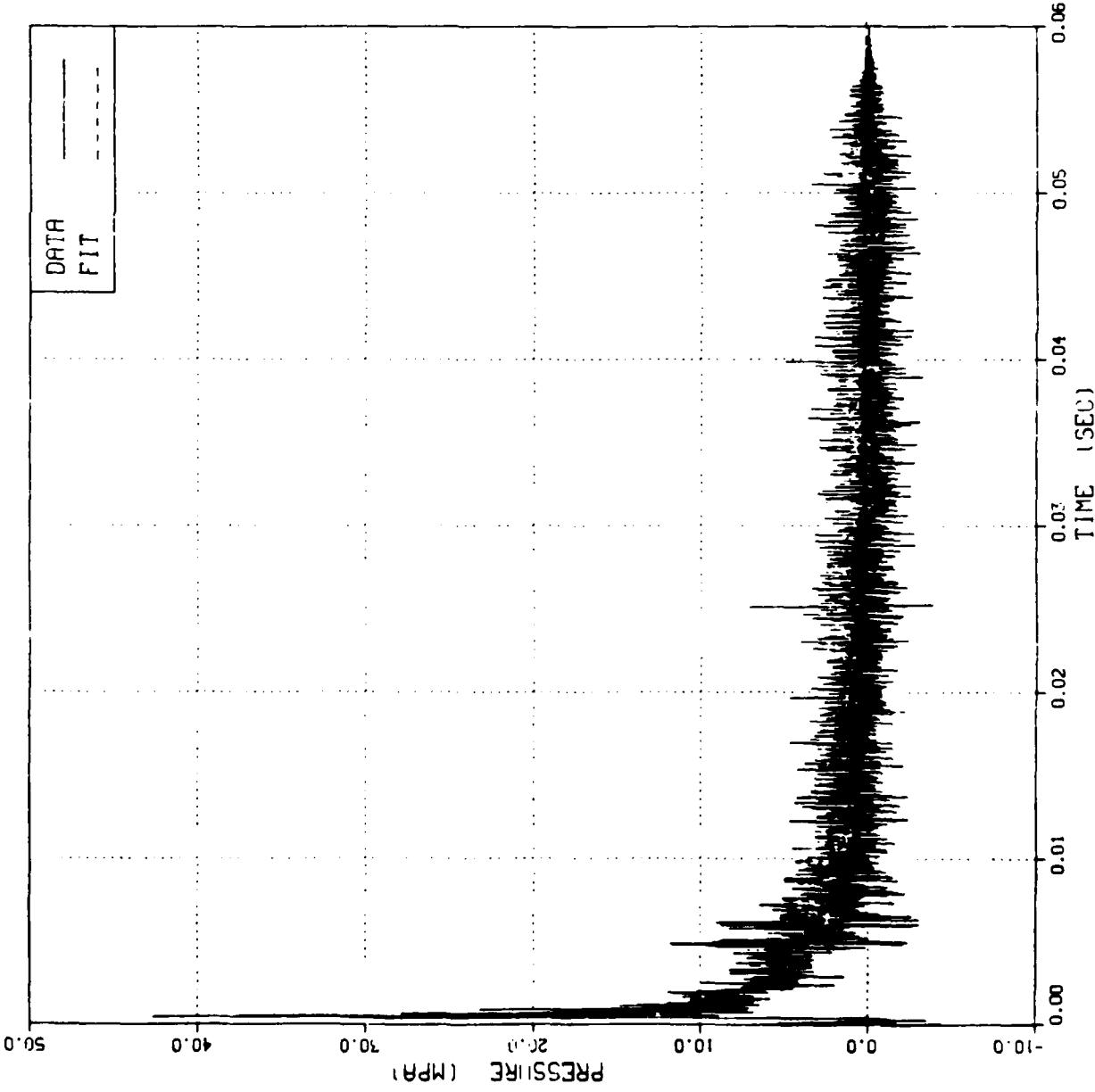


Figure 34

FOURFIT automated fit to 0.35  
KBAR DISC HEAT record AB-4:  
Fourier amplitude spectrum  
comparison.

DATA	FIT
YIELD (KT)	1.16
PSG (MPA)	37.32
RANGE (KM)	0.02775
POS. PHASE (SEC)	0.15789
TOA (SEC)	0.00178
LOW PASS FID (HZ)	500.

0.35 KBAR DISC HEST AB-7  
WITH FOURFIT SPEICHER-BROSC  
PRESSURE HISTORY



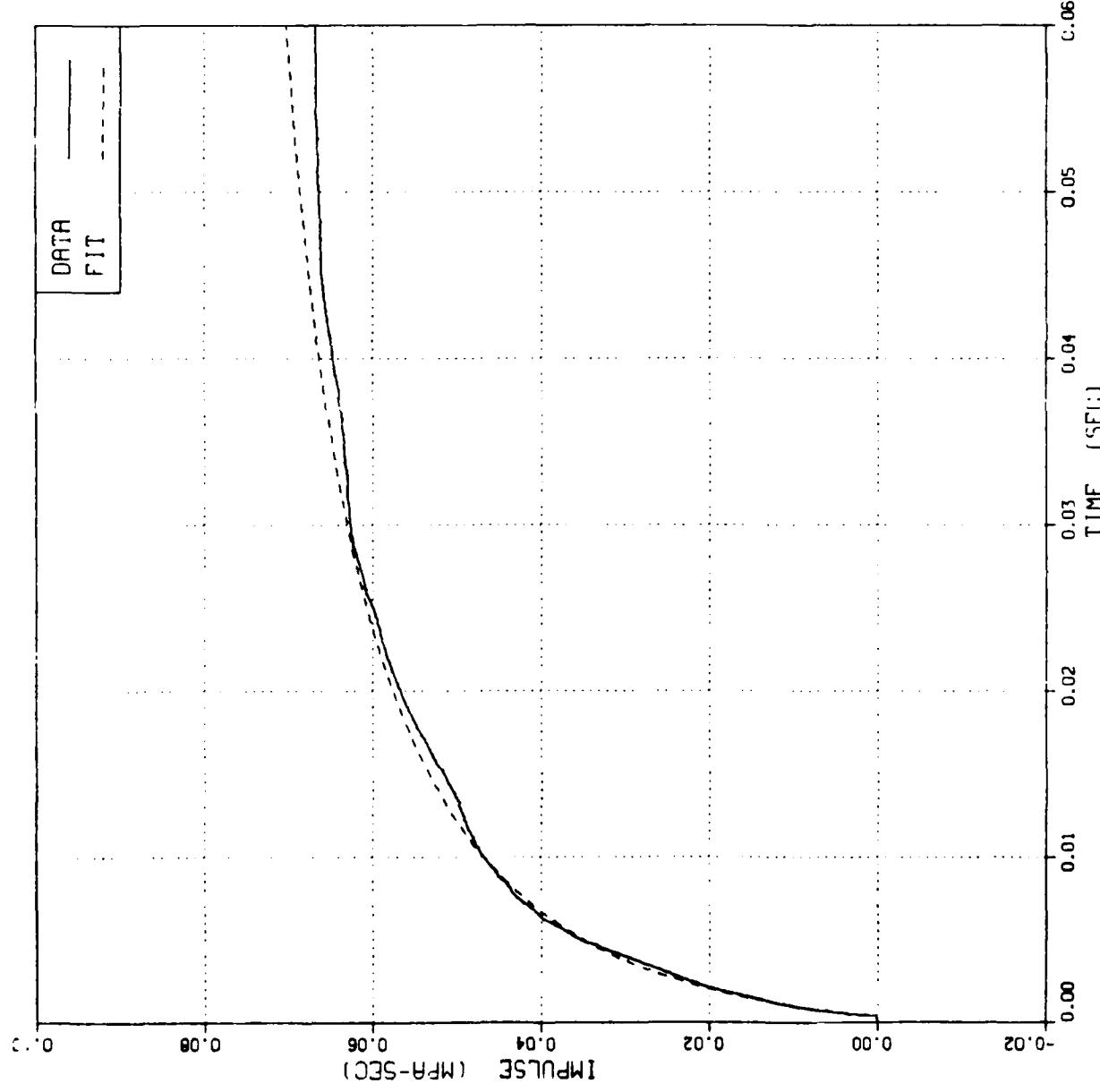
YIELD (KT) -	0.97
PSI (MPA) -	35.00
RANGE (KM) -	0.02676
POS. PHASE (SEC) -	0.14970
TOA (SEC) -	0.00178
LOW PASS FID (HZ) -	2000.

Figure 35

FOURFIT automated fit to 0.35  
KBAR DISC HEST record AB-7:  
pressure history comparison.

0.35 KBAR DISC HEST AB-7  
WITH FOURFIT SPEICHER-BRODE

IMPULSE HISTORY



114

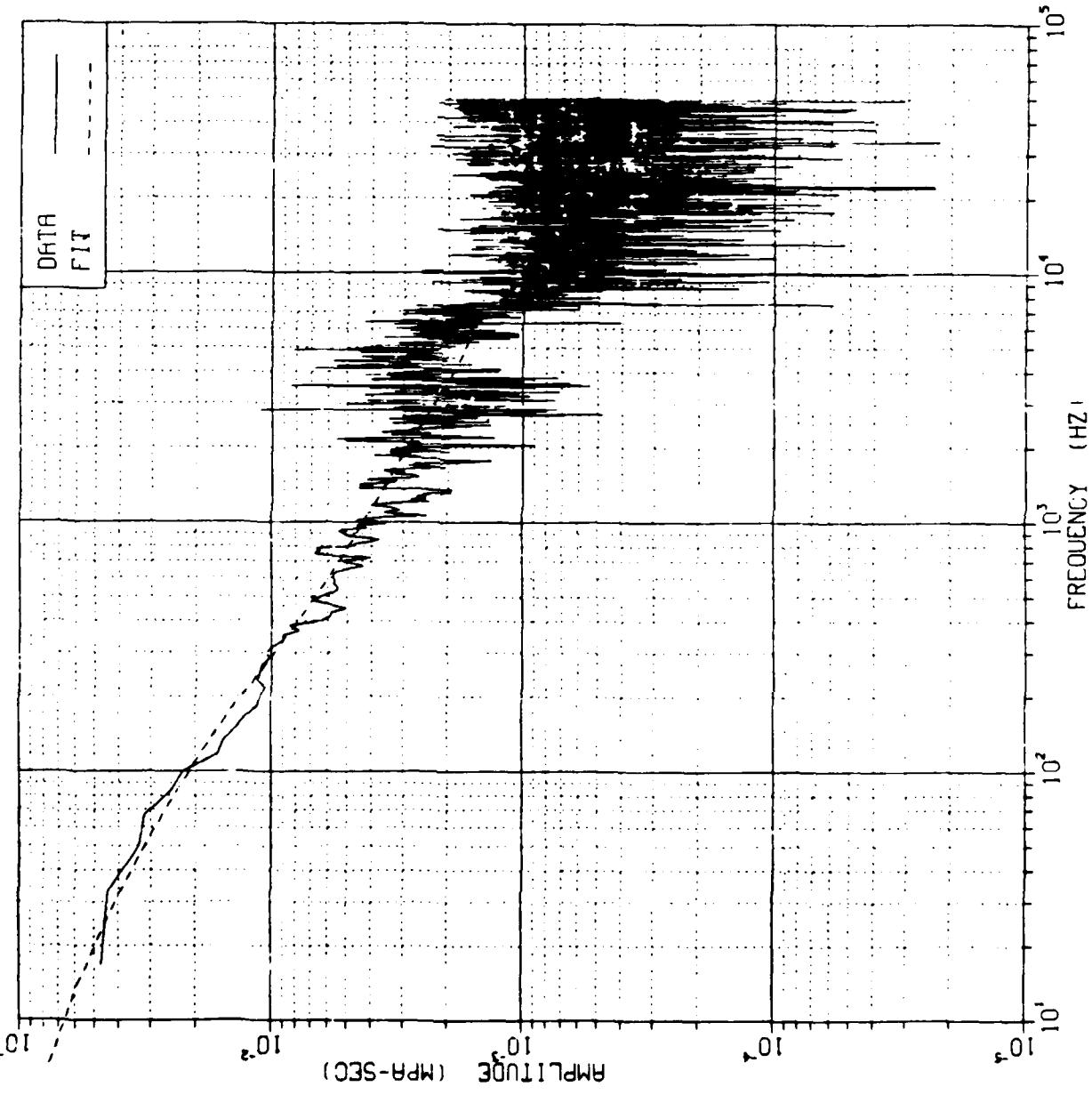
YIELD (KT)	-	0.97
PSO (MPA)	-	35.00
RANGE (KM)	-	0.02676
POS. PHASE (SEC)	-	0.14970
TOR (SEC)	-	0.00178
LOW PASS FID (HZ)	-	2000.

Figure 36

FOURFIT automated fit to 0.35  
KBAR DISC HEST record AB-7:  
impulse history comparison.

0.35 KBAR DISC HEST AB-7  
WITH FOURFIT SPEICHER-ERODE

FOURIER AMPLITUDE SPECTRUM



0.35 KBAR DISC HEST AB-9  
WITH FOURFIT SPEICHER-BRODE

PRESSURE HISTORY

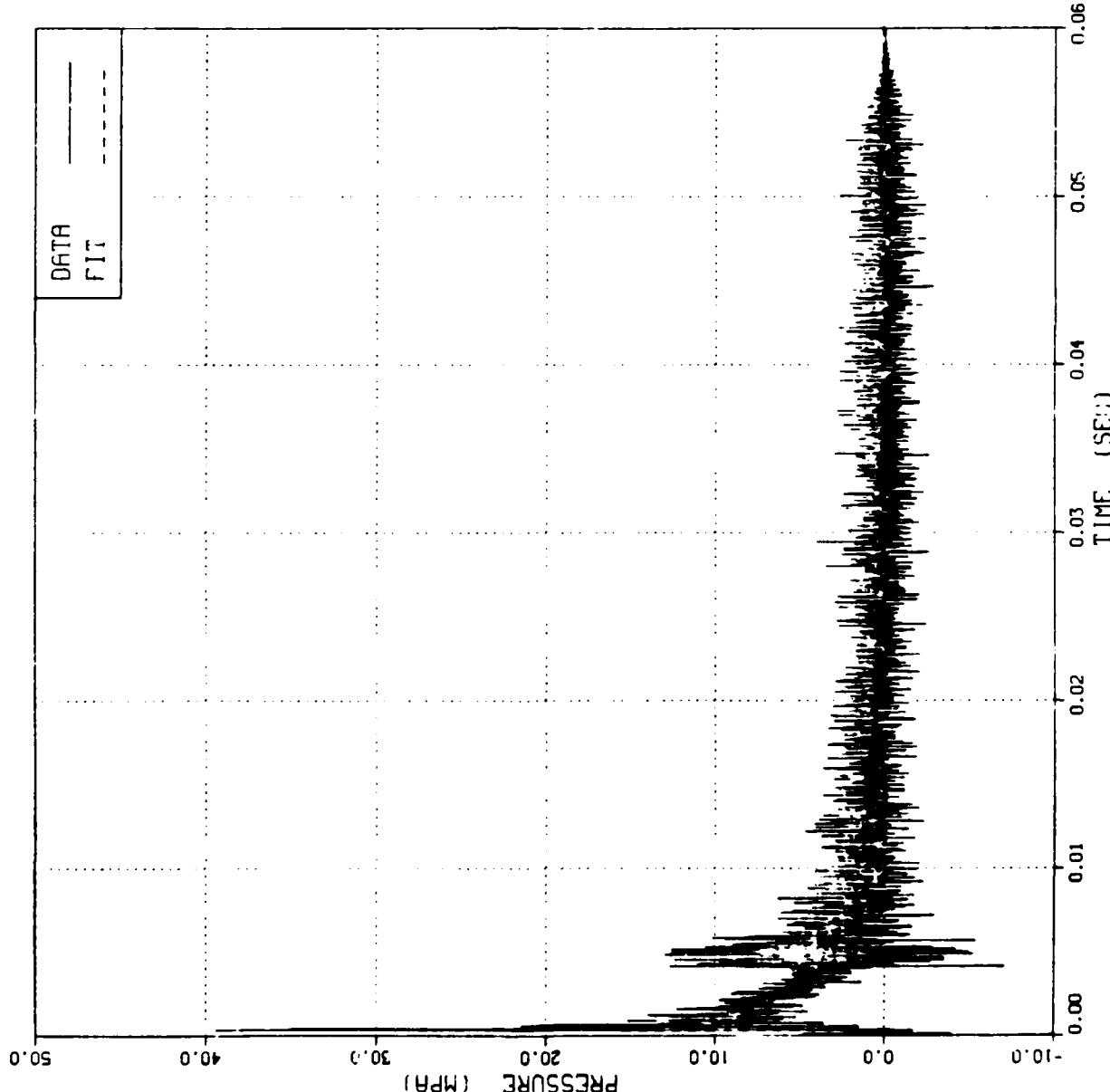
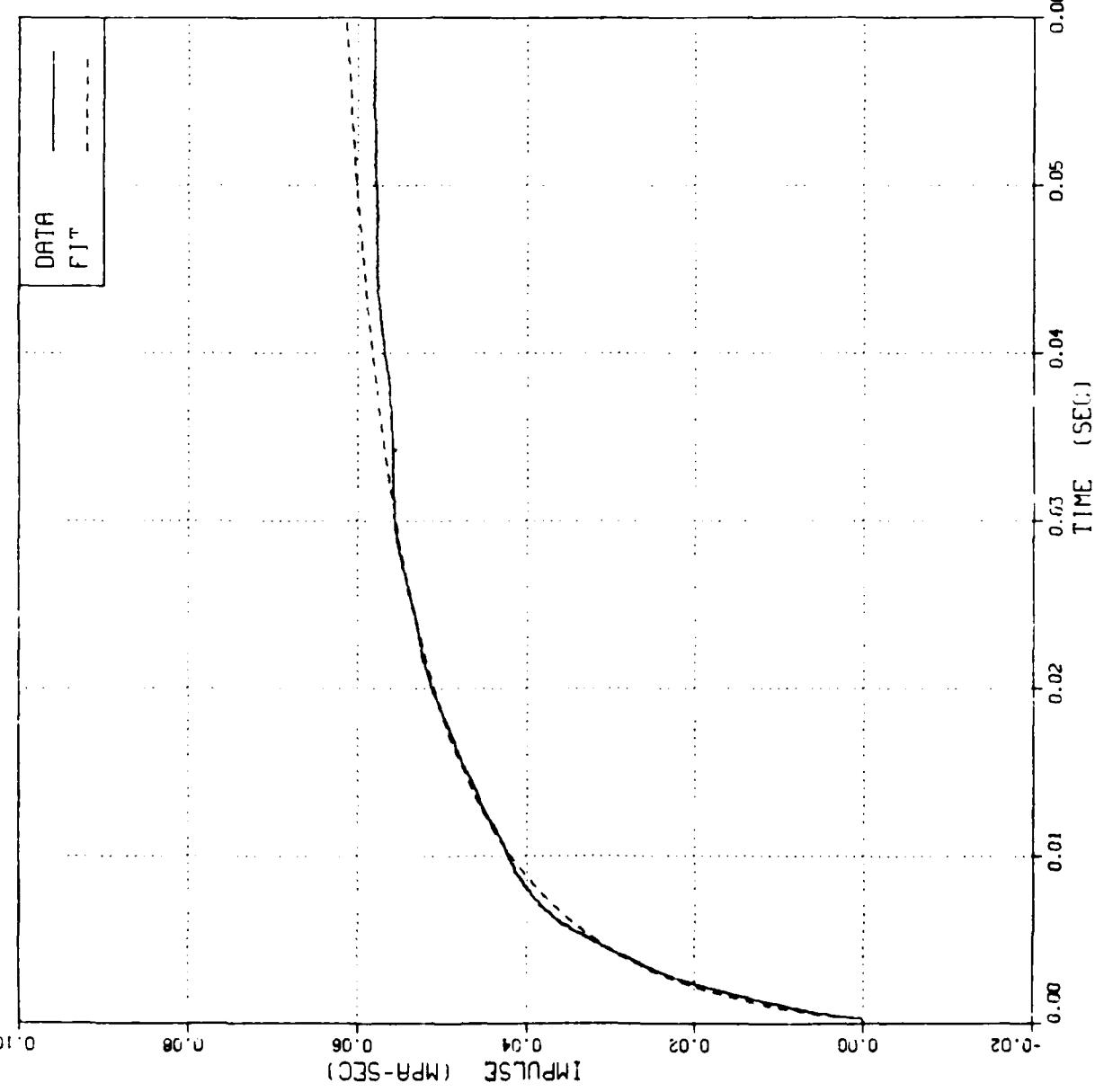


Figure 38

FOURFIT automated fit to 0.35  
KBAR DISC HEST record AB-9:  
pressure history comparison.

0.35 KBAR DISC HEST AB-9  
WITH FOURFIT SPEICHER-GRODE  
IMPULSE HISTORY



YIELD (KT) -	0.66
PSO (MPA) -	32.89
RANGE (KM) -	0.02408
POS. PHASE (SEC) -	0.13241
TOA (SEC) -	0.00166
LOW PASS FID (HZ) -	5000.

Figure 39

FOURFIT automated fit to  
0.35 KBAR DISC HEST record  
AB-9: impulse history  
comparison.

0.35 KBAR DISC HEST AB-9  
WITH FOURFIT SPEICHER-ERODE

FOURIER AMPLITUDE SPECTRUM

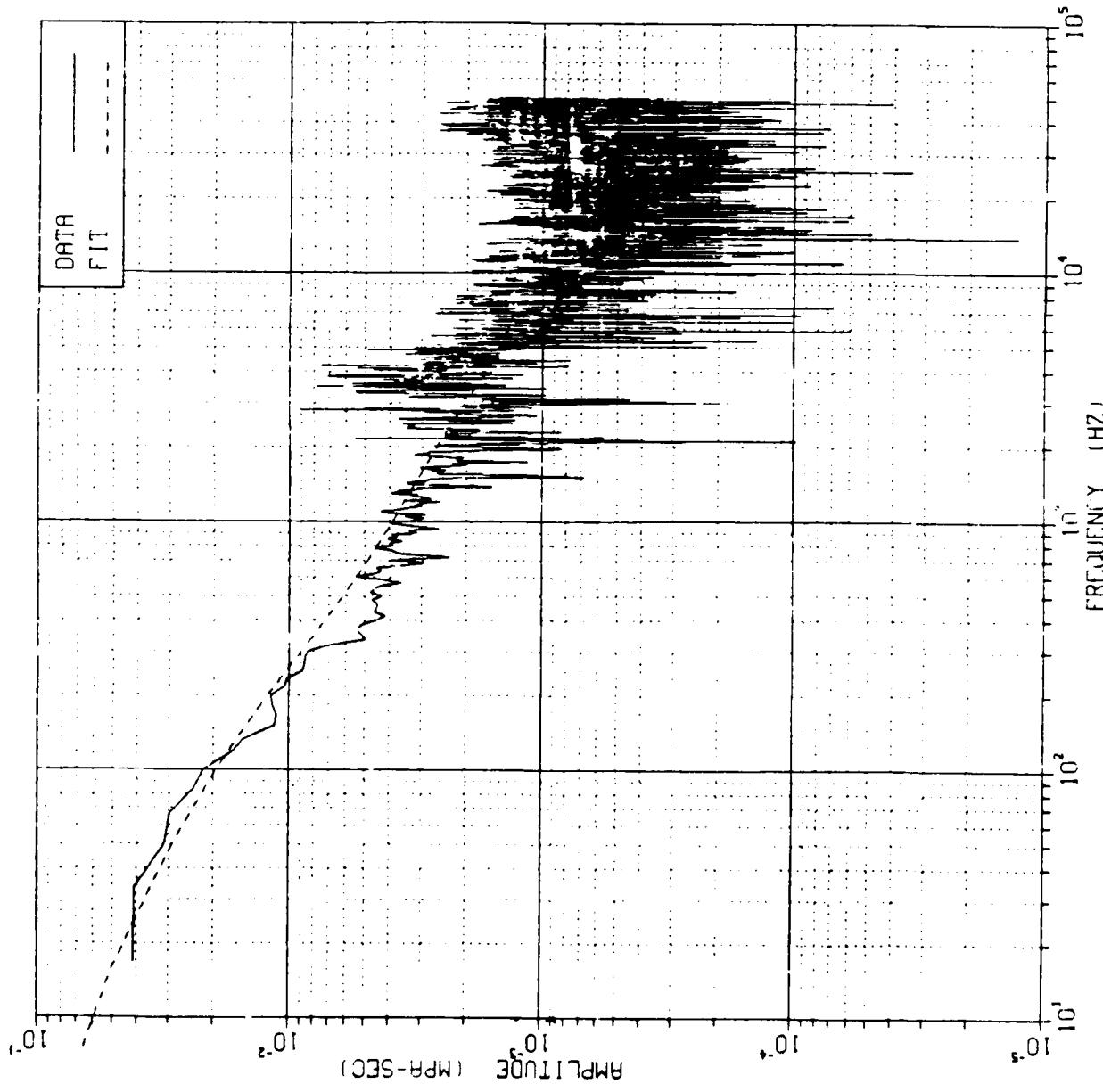


Figure 40

FOURFIT automated fit to  
0.35 KBAR DISC HEST  
record AB-9: Fourier  
amplitude spectrum comparison.

0.35 KBAR DISC HEST AB-10  
WITH FOURFIT SPEICHER-BRODE  
PRESSURE HISTORY

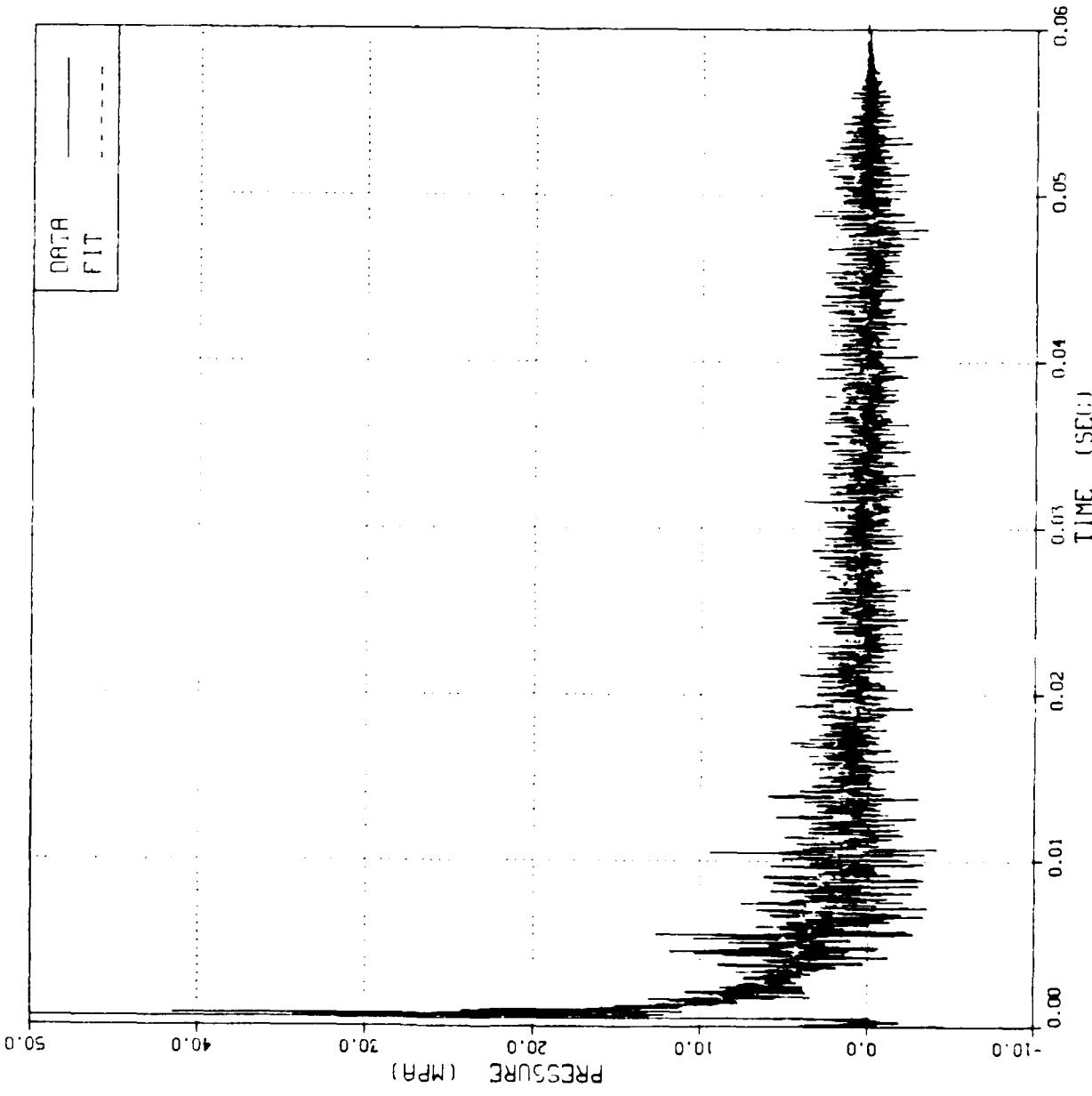
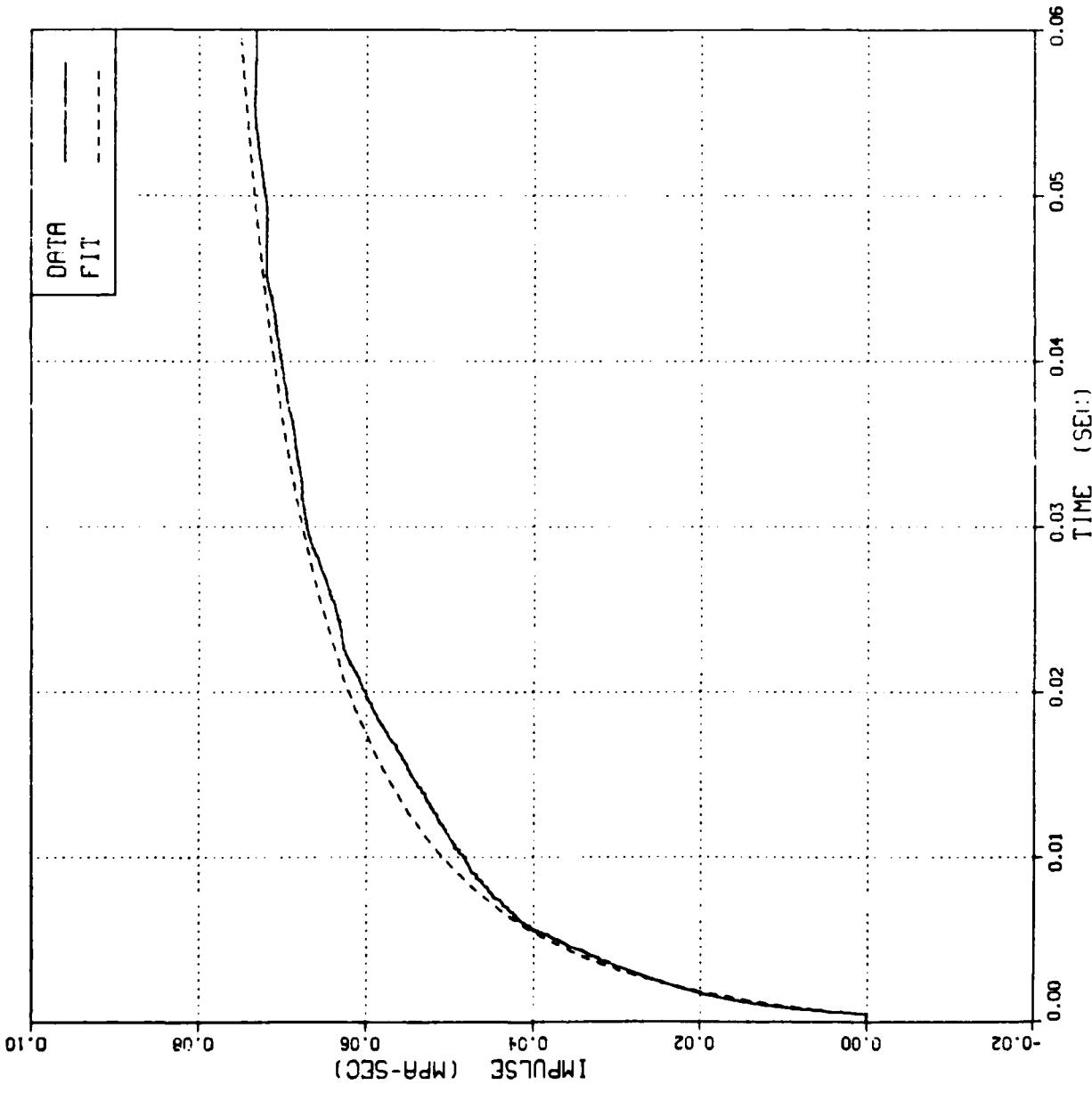


Figure 41

FOURFIT automated fit to 0.35  
KBAR DISC HEST record AB-10:  
pressure history comparison.

0.35 KBAR DISC HEST AB-10  
WITH FOURFIT SPEICHER-BRODE

IMPULSE HISTORY



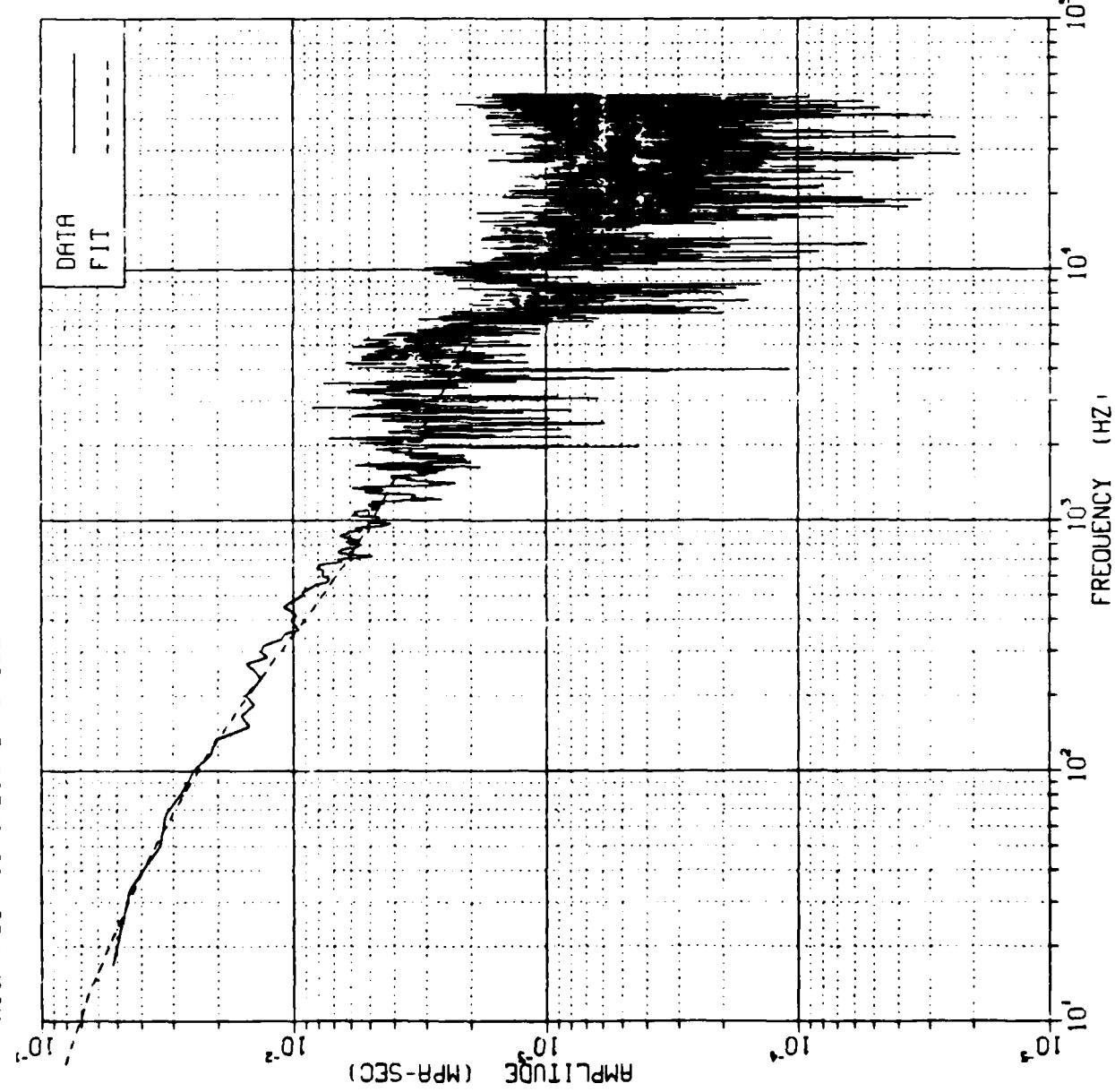
YIELD (KT) -	0.99
PSC (MPA) -	41.71
RANGE (KM) -	0.02542
POS. PHASE (SEC) -	0.14882
TOA (SEC) -	0.00153
LOW PASS FID (HZ) -	2000.

Figure 42

FOURFIT automated fit to  
0.35 KBAR DISC HEST record  
AB-10: impulse history  
comparison.

0.35 KBAR DISC HEST AB-10  
WITH FOURFIT SPEICHER-BRODE

FOURIER AMPLITUDE SPECTRUM



YIELD (KT) -	0.99
PSO (MPA) -	41.71
RANGE (KM) -	0.02542
POS. PHASE (SEC) -	0.14882
TOA (SEC) -	0.00153
LOW PASS FID (HZ) -	2000.

Figure 43

FOURFIT automated fit to  
0.35 KBAR DISC HEST record  
AB-10: Fourier amplitude  
spectrum comparison.

0.35 KBAR DISC HEST AB-12  
WITH FOURFIT SPEICHER-BRODE

PRESSURE HISTORY

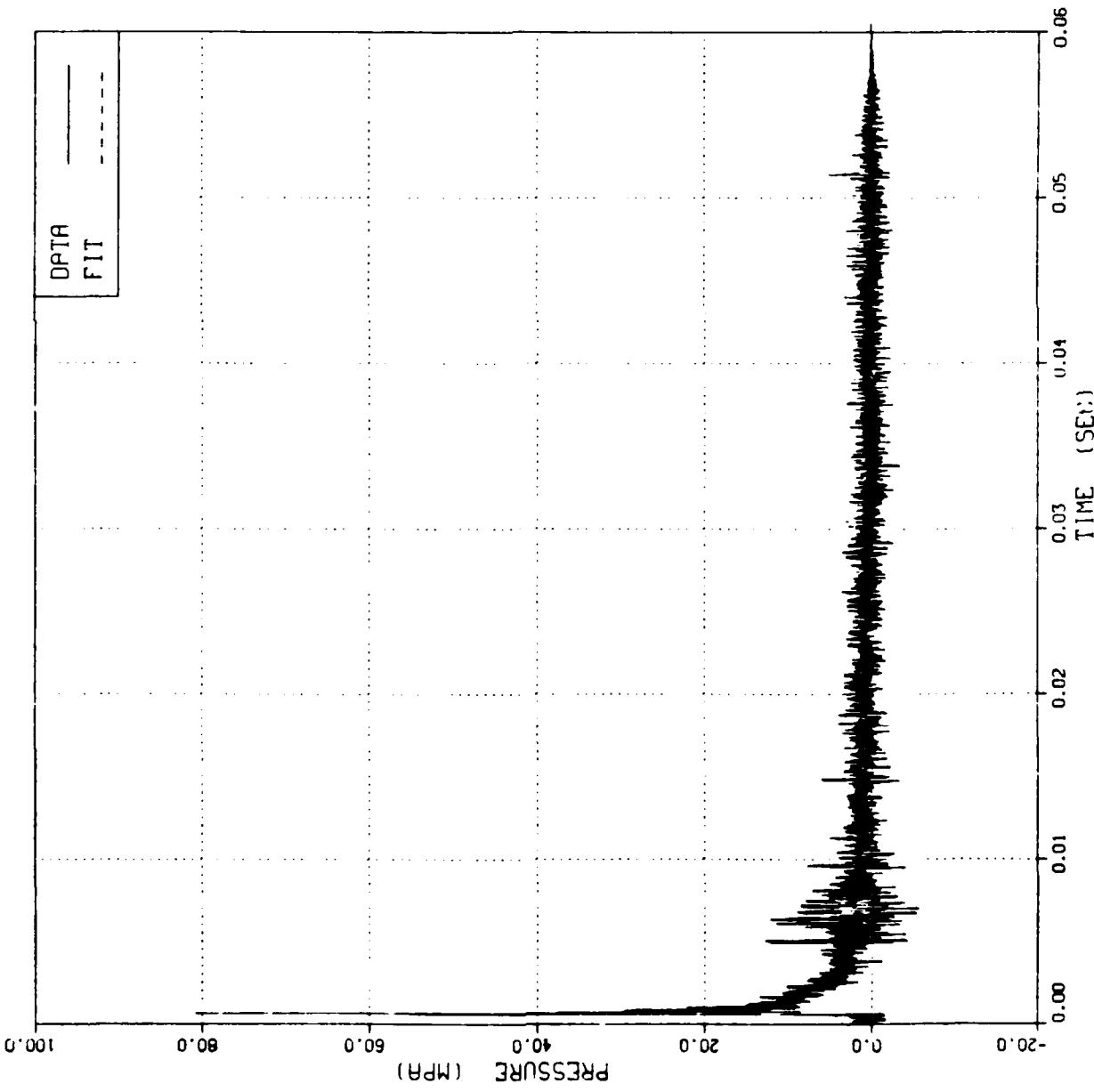
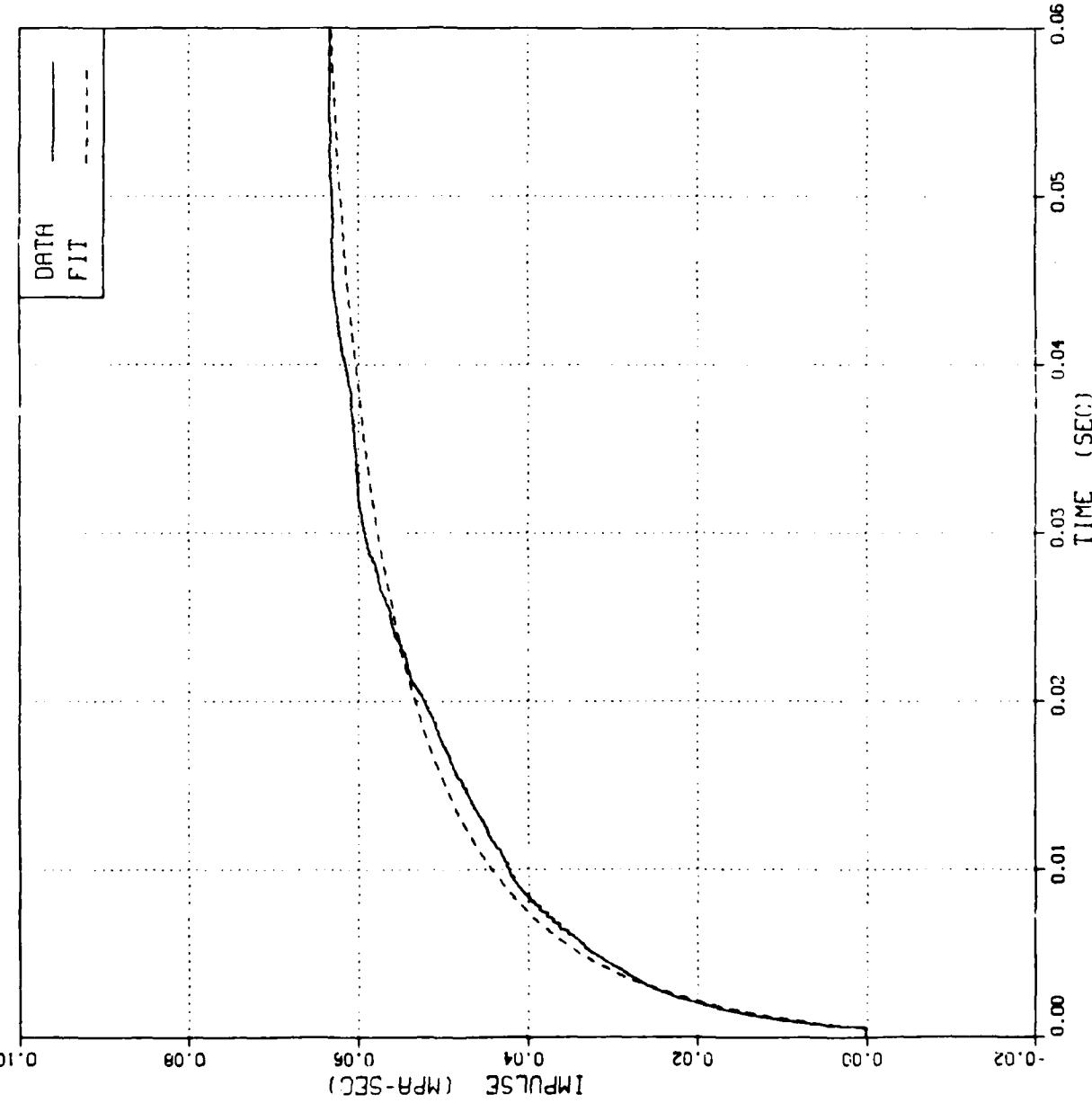


Figure 44

FOURFIT automated fit to  
0.35 KBAR DISC HEST record  
AB-12: pressure history  
comparison.

0.35 KBAR DISC HEAT AB-12  
WITH FOURFIT SPEICHER-BRODE

IMPULSE HISTORY



0.35 KBAR DISC HEAT AB-12  
WITH FOURFIT SPEICHER-BRODE

FOURIER AMPLITUDE SPECTRUM

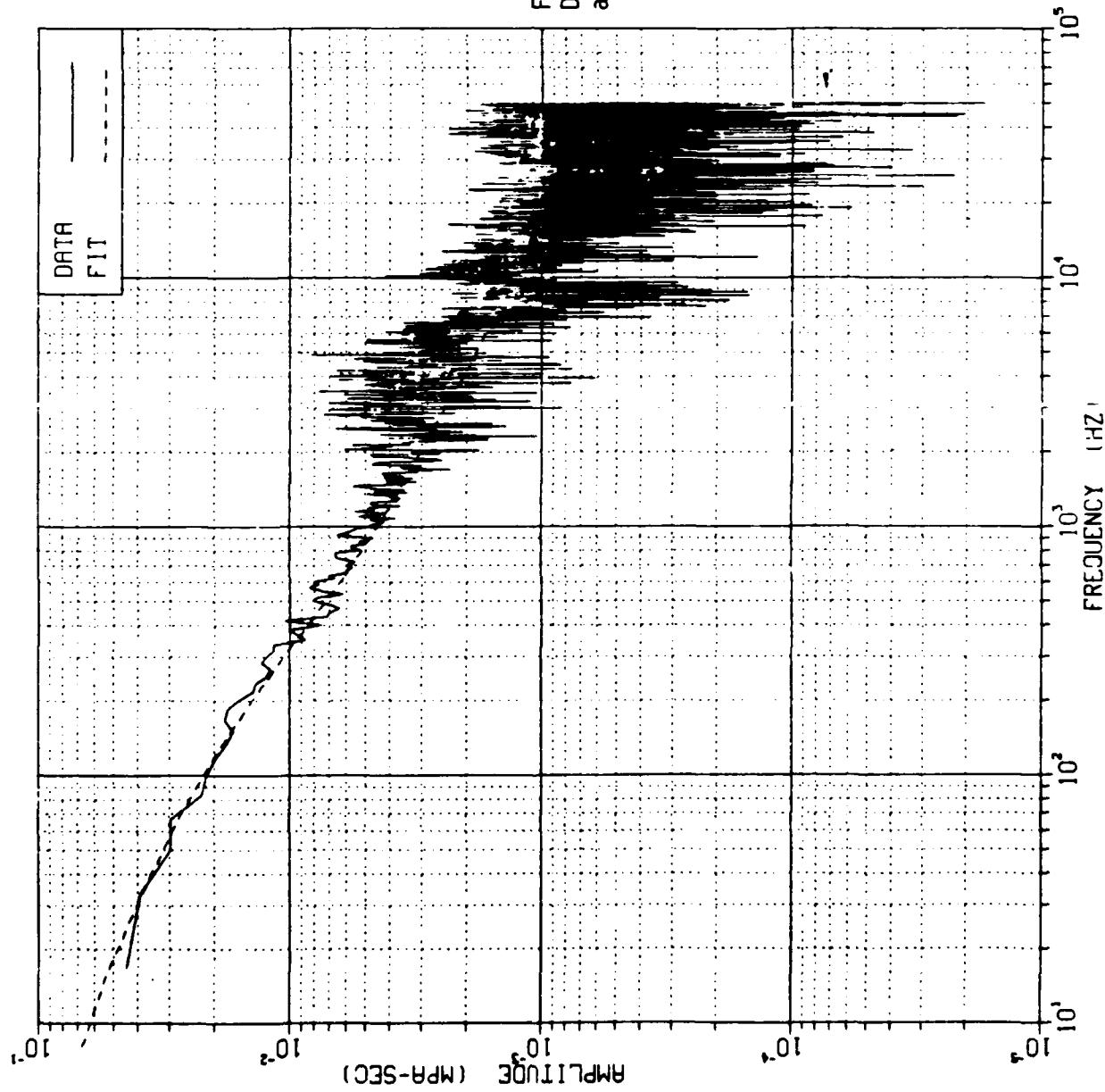
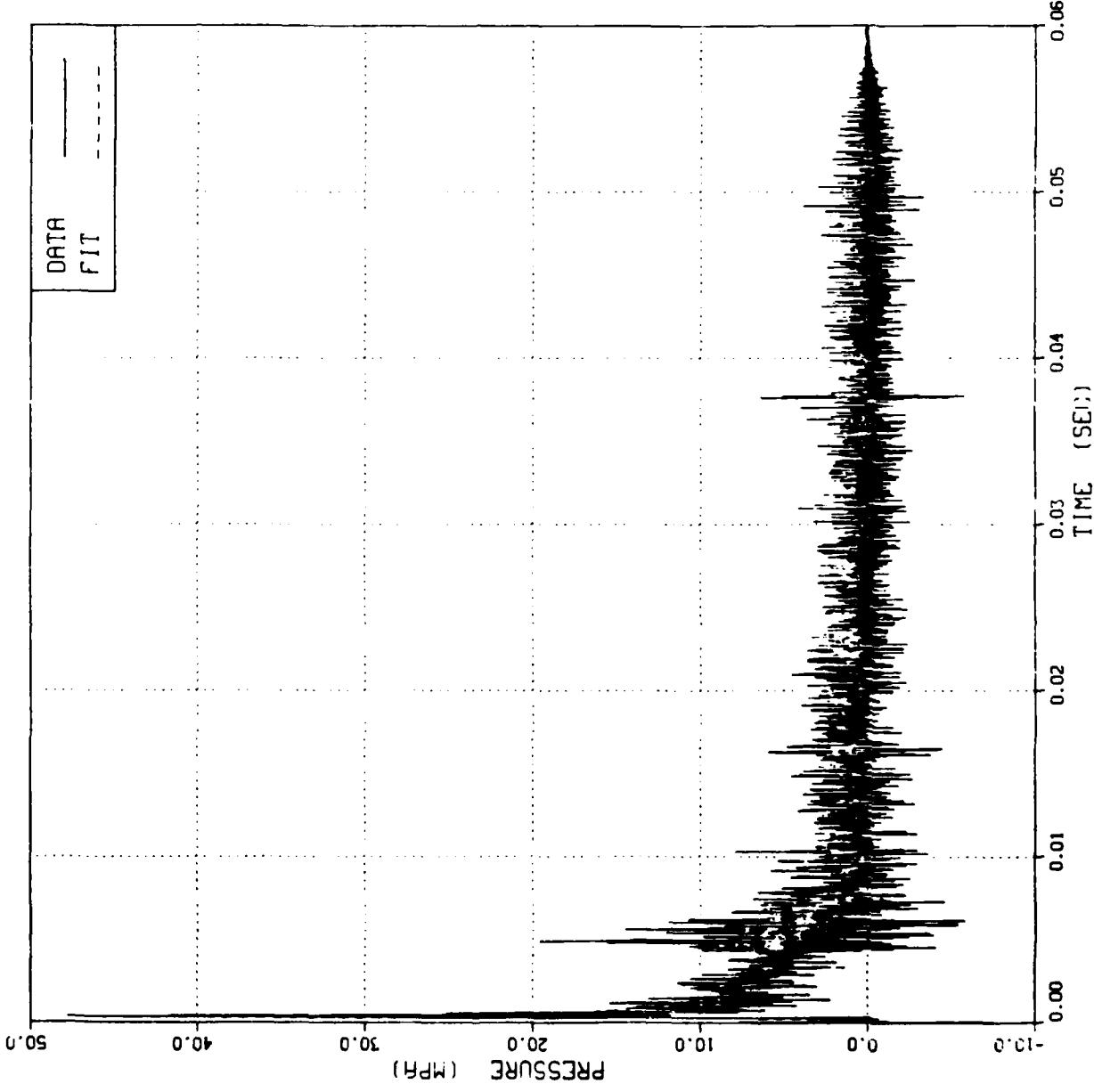


Figure 46

0.35 KBAR DISC HEAT AB-13  
WITH FOURFIT SPEICHER-BRODE

PRESSURE HISTORY



0.35 KBAR DISC HEST AB-13  
WITH FOURFIT SPEICHER-BRODE

IMPULSE HISTORY

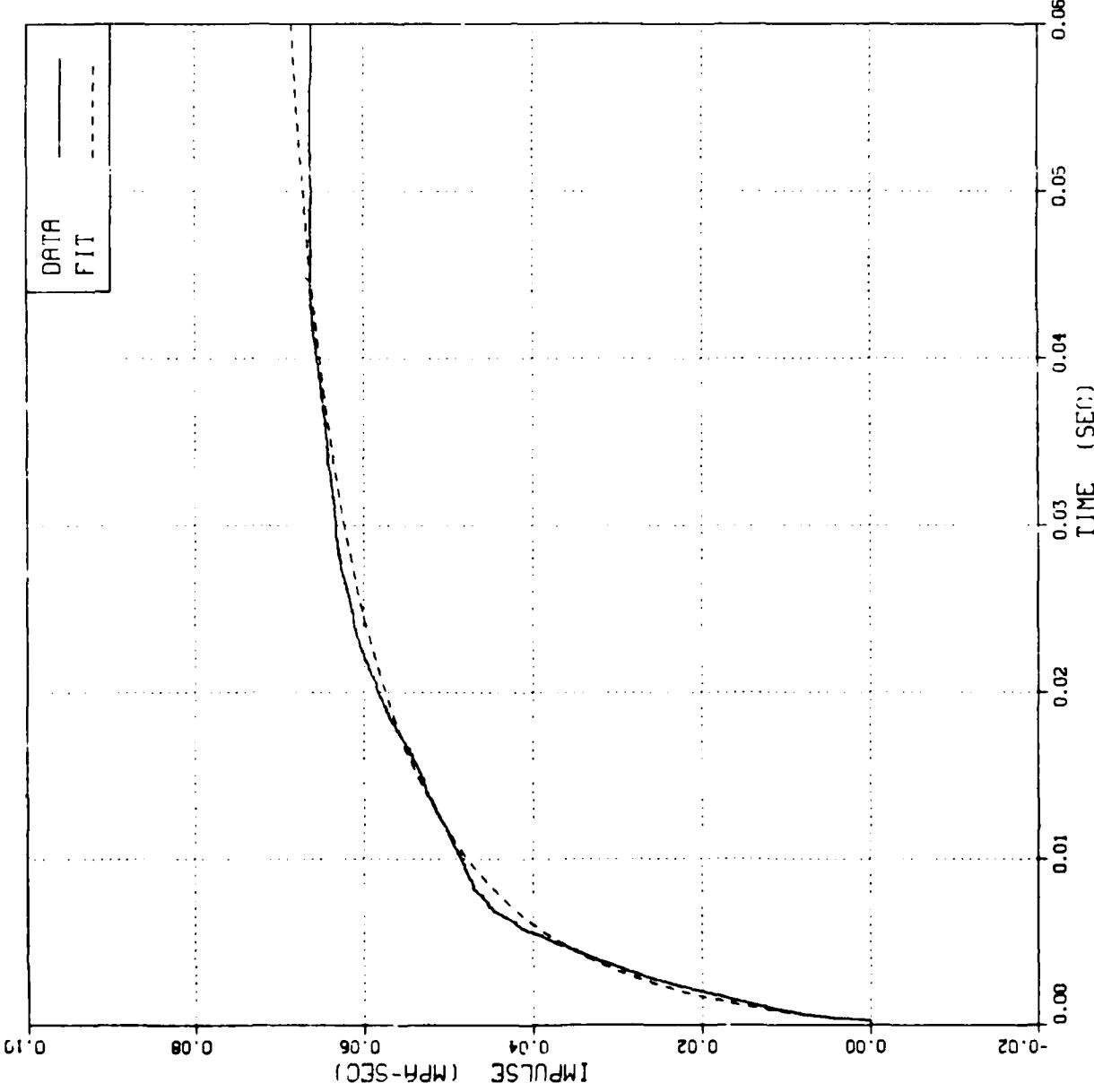
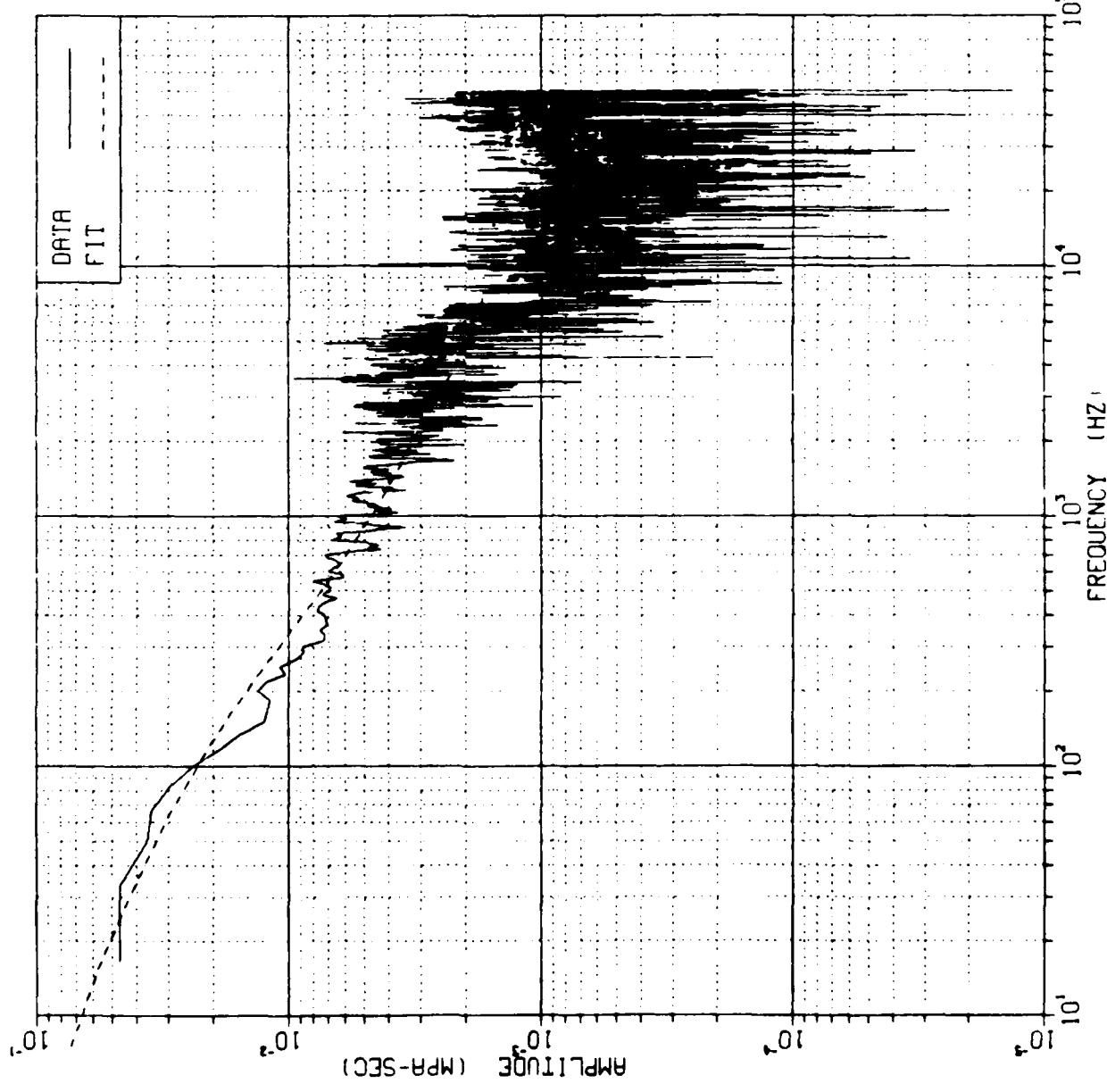


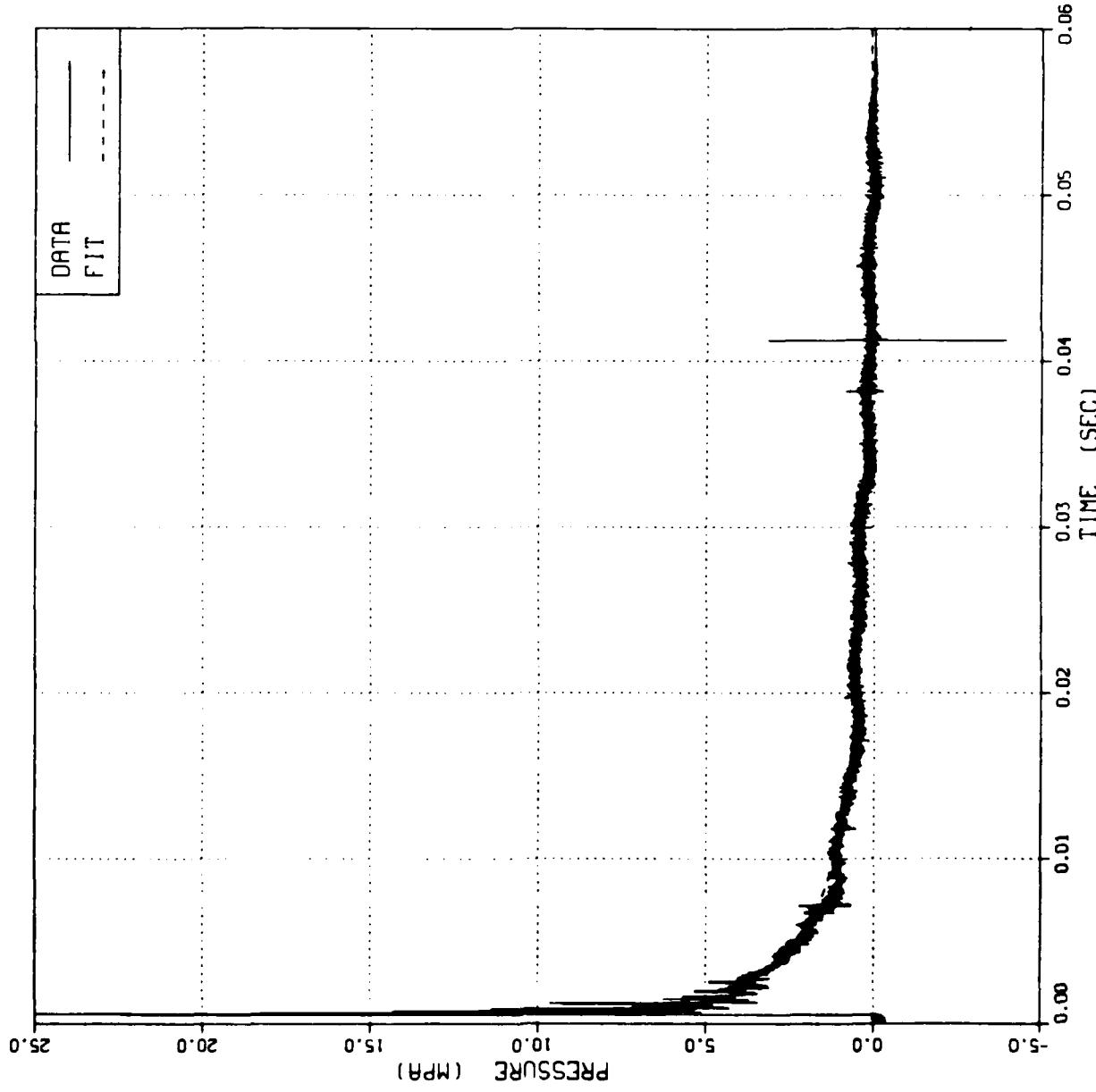
Figure 48

FOURFIT automated fit to  
0.35 KBAR DISC HEST record  
AB-13: impulse history  
comparison.

0.35 KBAR DISC HEST AB-13  
WITH FOURFIT SPEICHER-ERODE

FOURIER AMPLITUDE SPECTRUM





YIELD (KT) -	0.59
PSO (MPA) -	15.59
RANGE (KM) -	0.02977
POS. PHASE (SEC) -	0.13188
TOA (SEC) -	0.00312
LOW PASS FID (HZ) -	2000.

Figure 50

FOURFIT automated fit to  
0.35 KBAR HEST record 51:  
pressure history comparison.

0.35 KBAR HEST 51  
WITH FOURFIT SPEICHER-BRODE

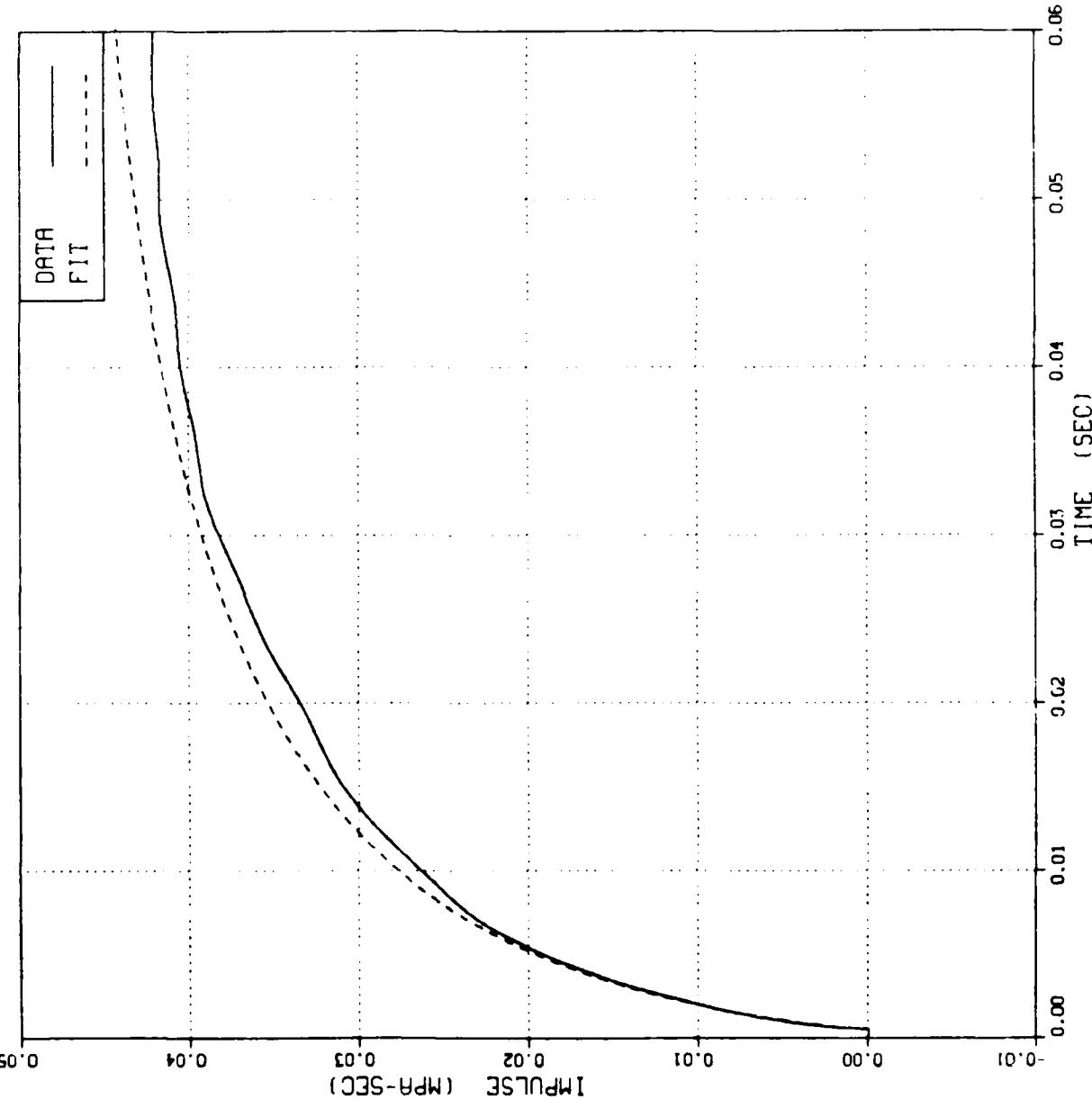
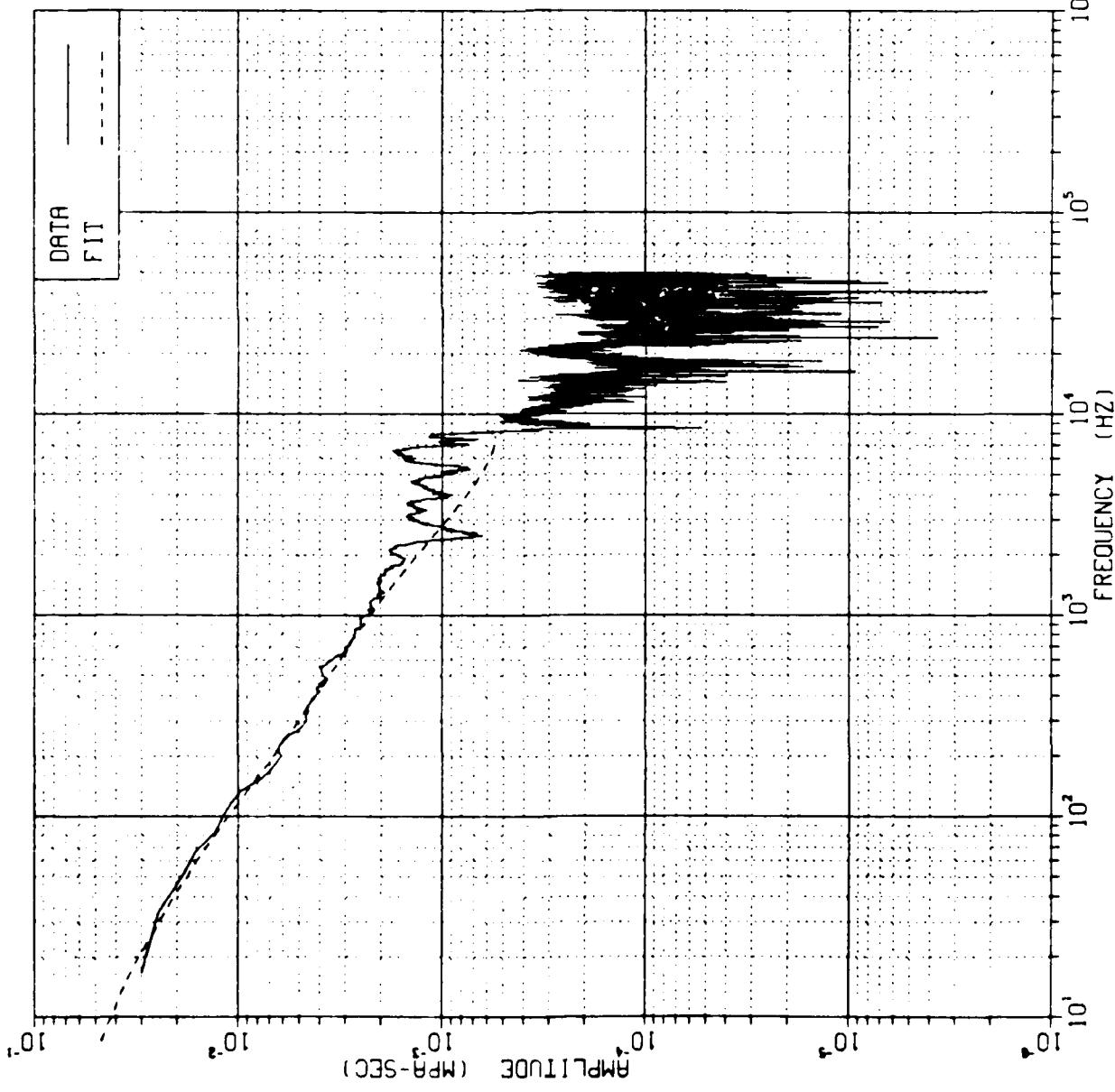


Figure 51  
FOURFIT automated fit to  
0.35 KBAR HEST record 51:  
impulse history comparison.

0.35 KBAR HEST 51  
WITH FOURFIT SPEICHER-BRODE

FOURIER AMPLITUDE SPECTRUM

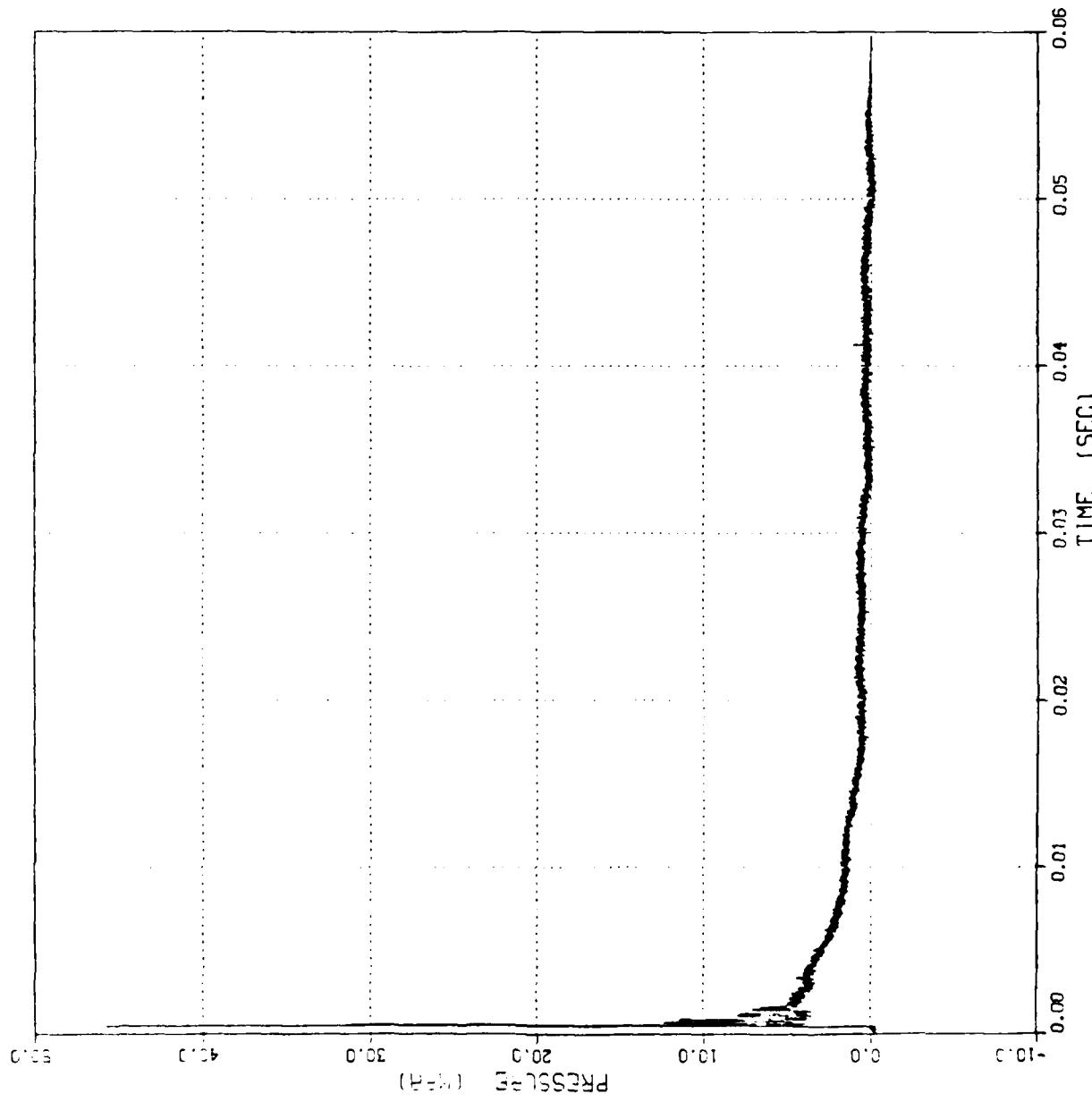


DATA	FIT
YIELD (KT)	0.59
PSO (MPA)	15.59
RANGE (KM)	0.02977
POS. PHASE (SEC)	0.13188
TOA (SEC)	0.00312
LOW PASS FID (HZ)	2000.

Figure 52

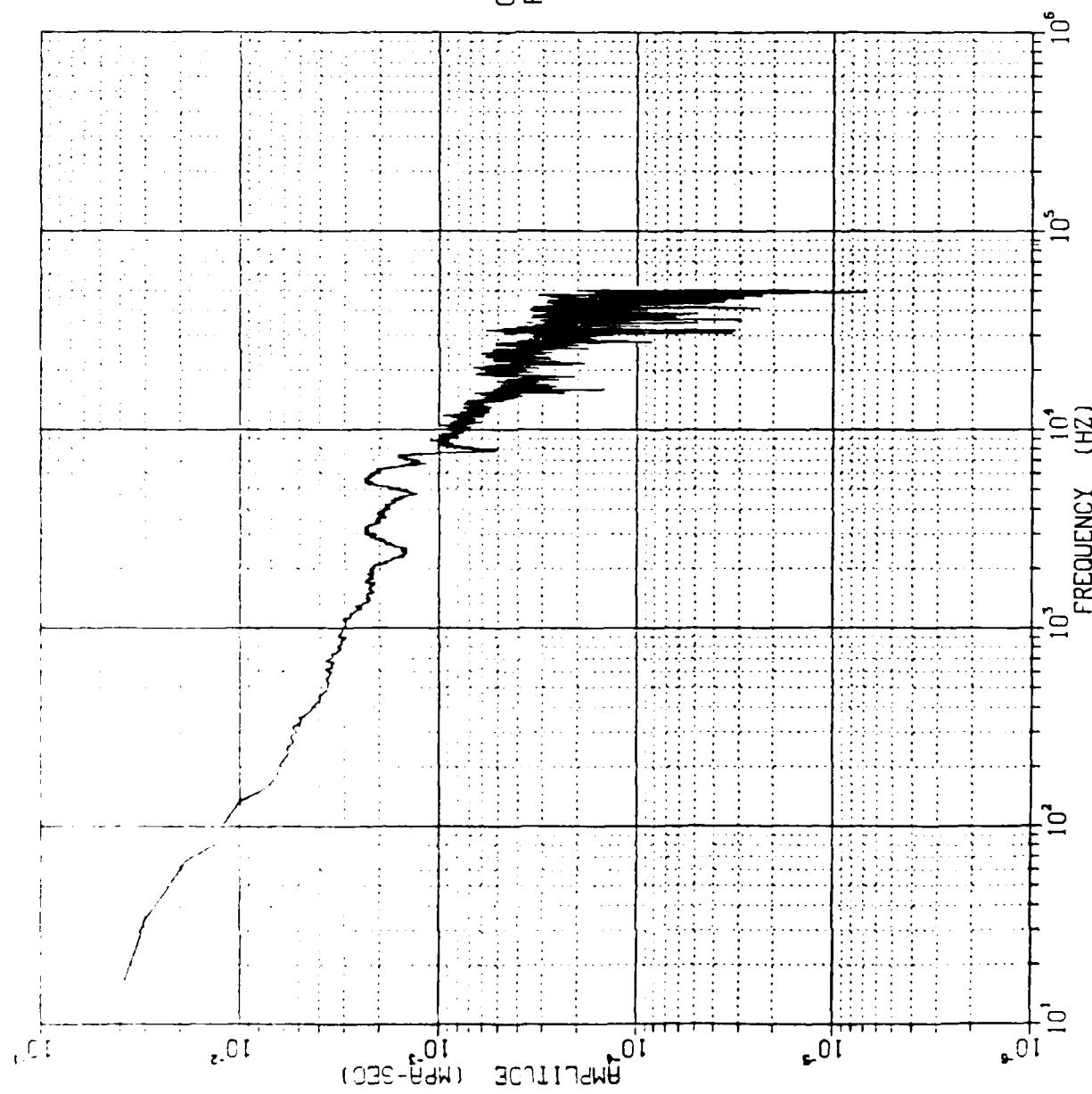
FOURFIT automated fit to 0.35  
KBAR HEST record 51: Fourier  
amplitude spectrum comparison.

0.35 KBAR HEST 417 PRESSURE HISTORY



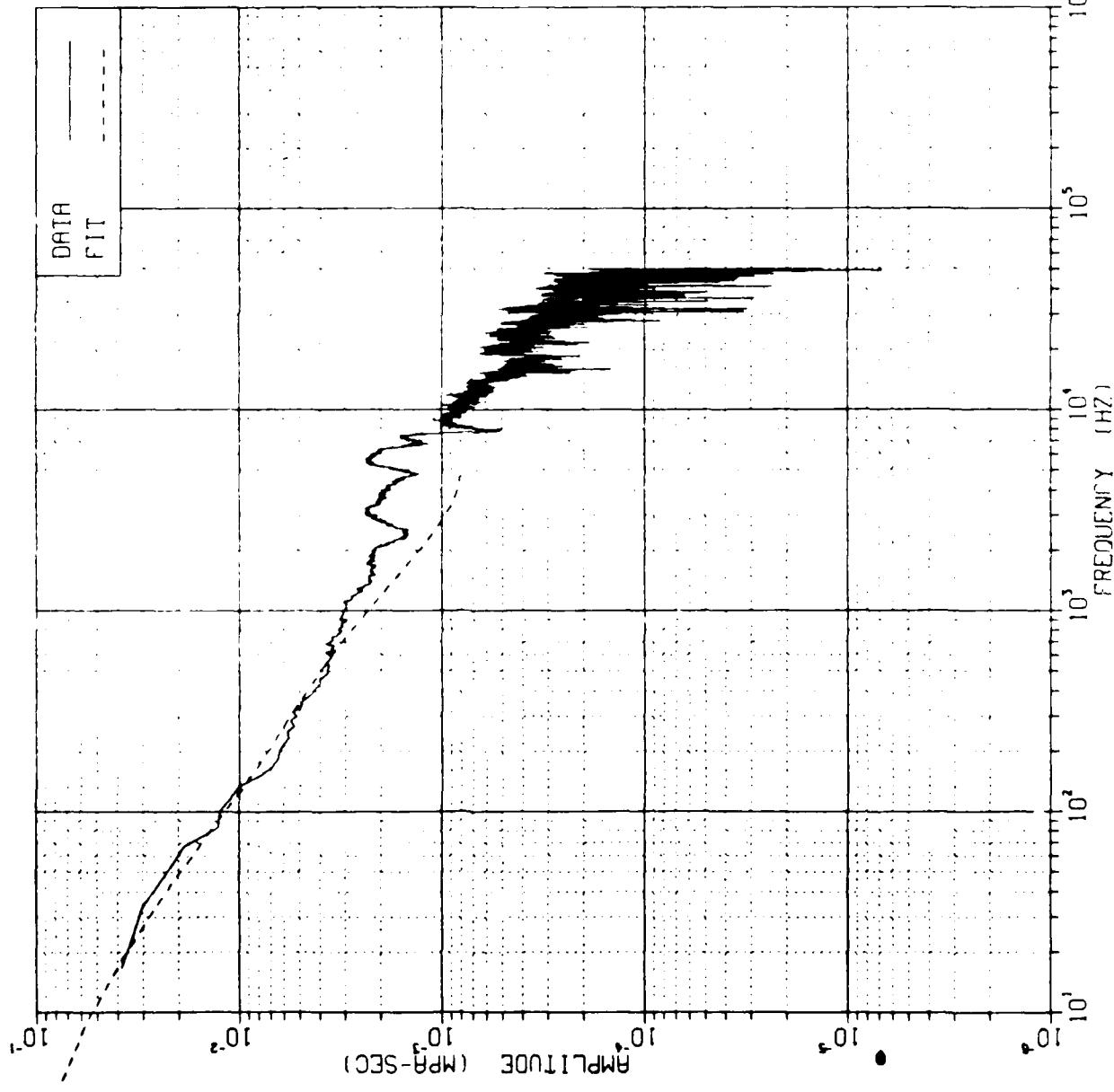
0.35 KBAR HEST

FOURIER AMPLITUDE SPECTRUM



0.35 KBAR HEST 417  
WITH FOURFIT SPEICHER-BRODE

FOURIER AMPLITUDE SPECTRUM



DATA	FIT
YIELD (KT)	2.71
PSO (MPA)	13.99
RANGE (KM)	0.05132
POS. PHASE (SEC)	0.21951
TOR (SEC)	0.00571
LOW PASS FID (HZ)	1000.

0.35 KBAR HEST 417  
WITH FOURFIT SPEICHER-BRODE

PRESSURE HISTORY

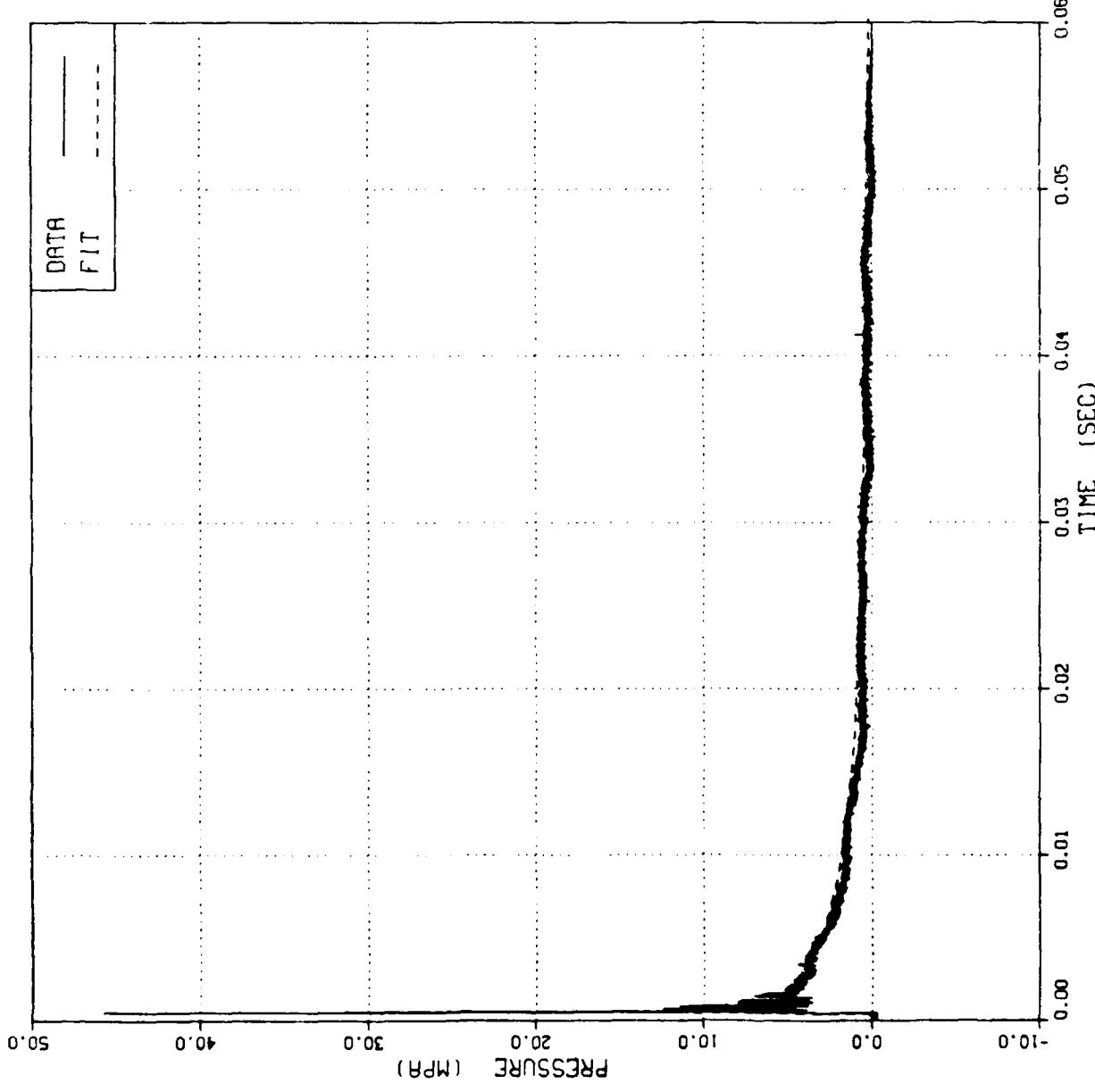


Figure 56

FOURFIT automated fit to 0.35  
KBAR HEST record 417: pressure  
history comparison.

0.35 KBAR HEAT 417  
WITH FOURFIT SPEICHER-BRODE

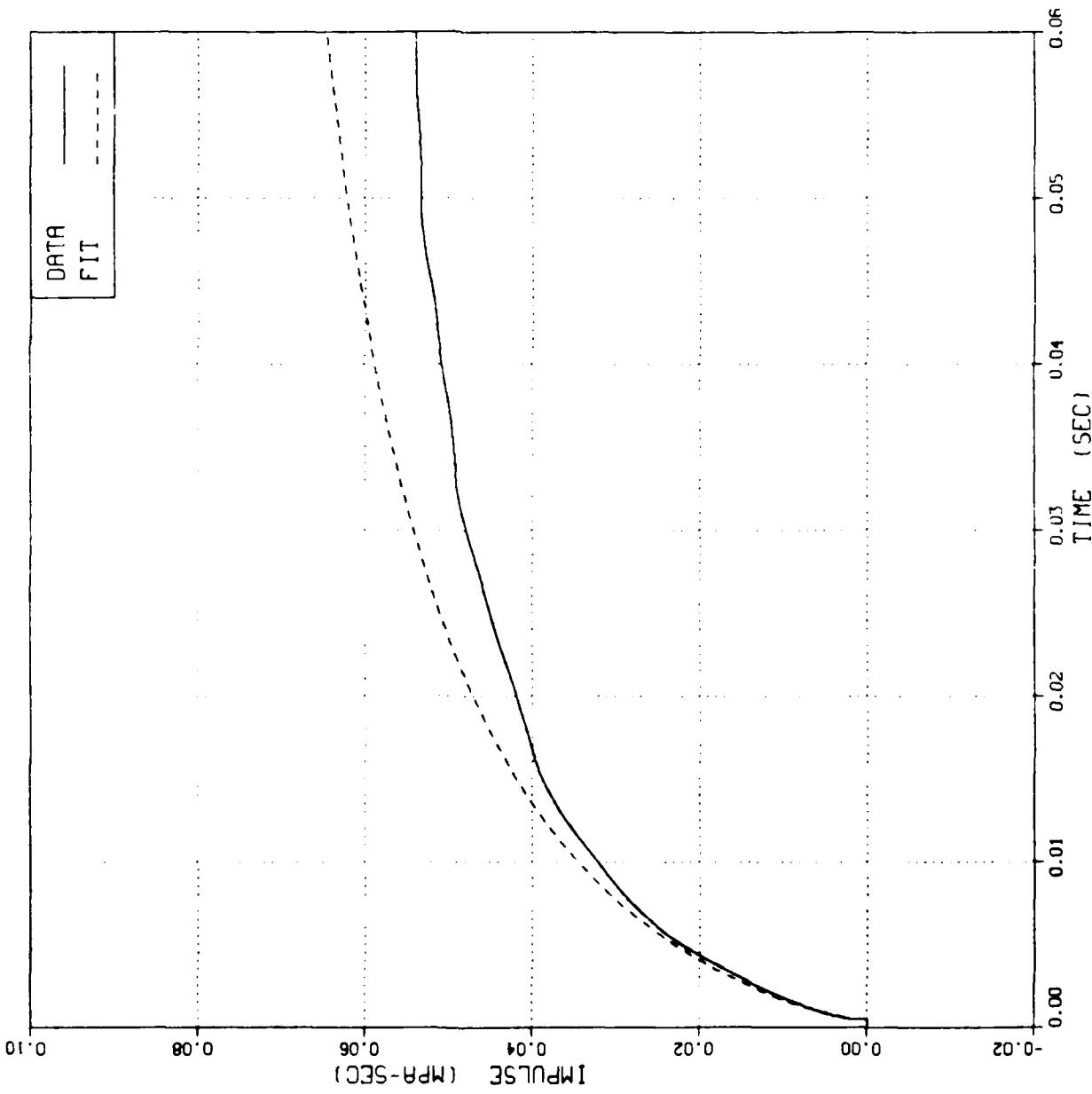


Figure 57

FOURFIT automated fit to 0.35  
KBAR HEAT record 417: impulse  
history comparison.

0.35 KBAR HEST 411  
WITH FOURFIT SPEICHER-BRODE

PRESSURE HISTORY

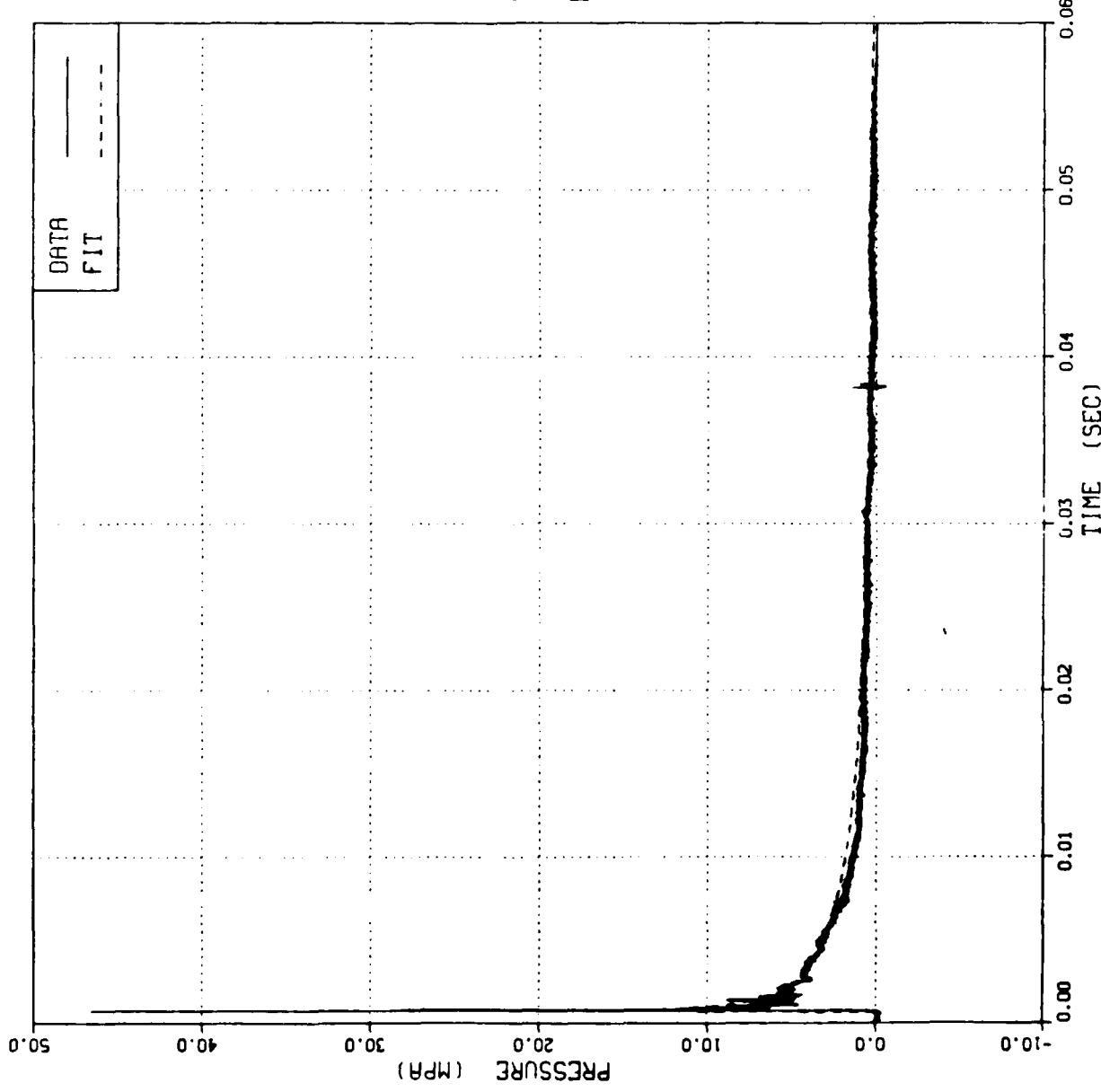
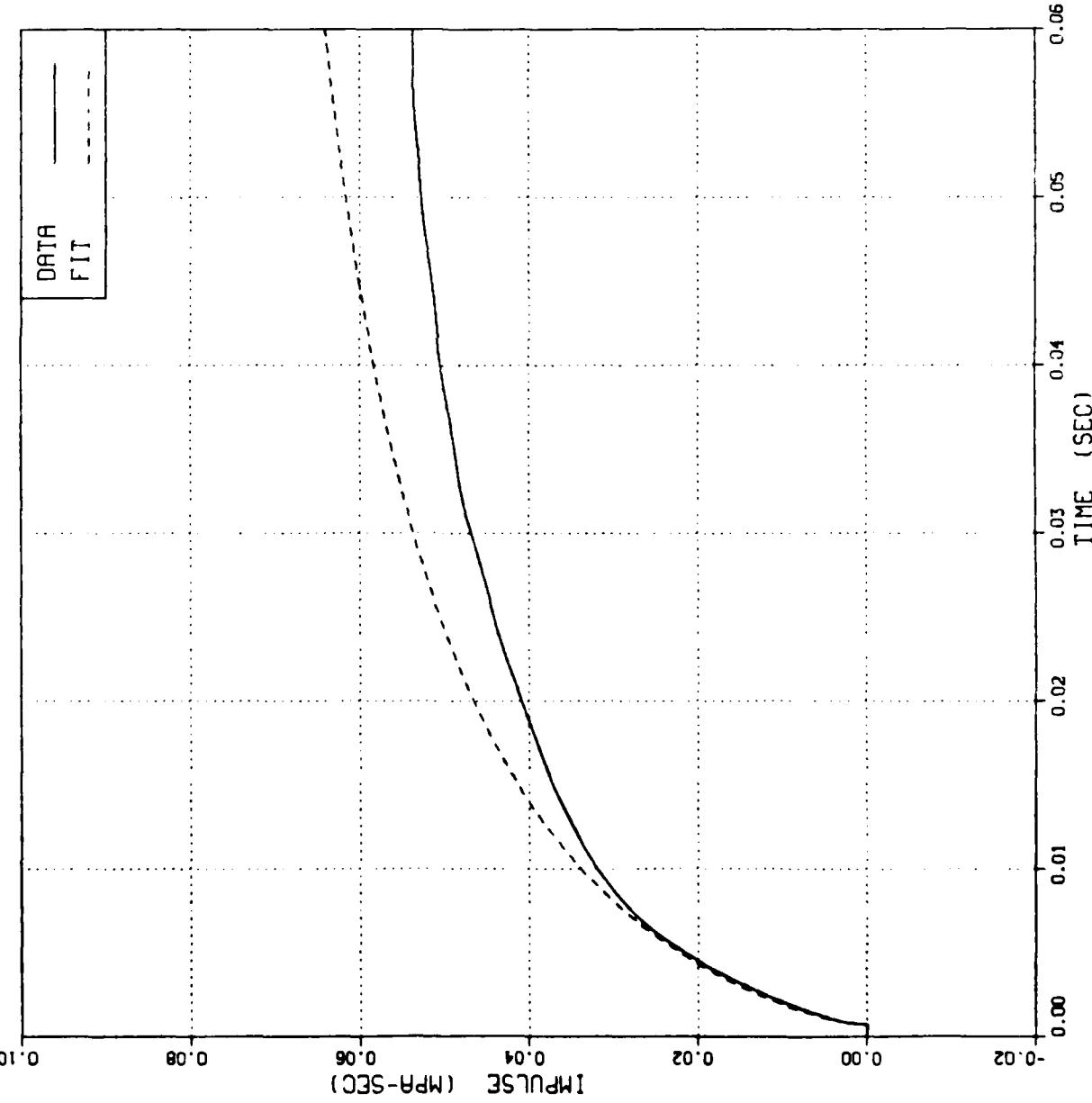


Figure 58

FOURFIT automated fit to 0.35  
KBAR HEST record 411: pressure  
history comparison.

0.35 KBAR HEST 411  
WITH FOURFIT SPEICHER-BRODE



YIELD (KT) -	2.67
PSO (MPA) -	13.89
RANGE (KM) -	0.05125
POS. PHASE (SEC) -	0.21867
TOA (SEC) -	0.00572
LOW PASS FID (HZ) -	1000.

Figure 59

FOURFIT automated fit to  
0.35 KBAR HEST record 411:  
impulse history comparison.

0.35 KBAR HEST 411  
WITH FOURFIT SPEICHER-BRODE

FOURIER AMPLITUDE SPECTRUM

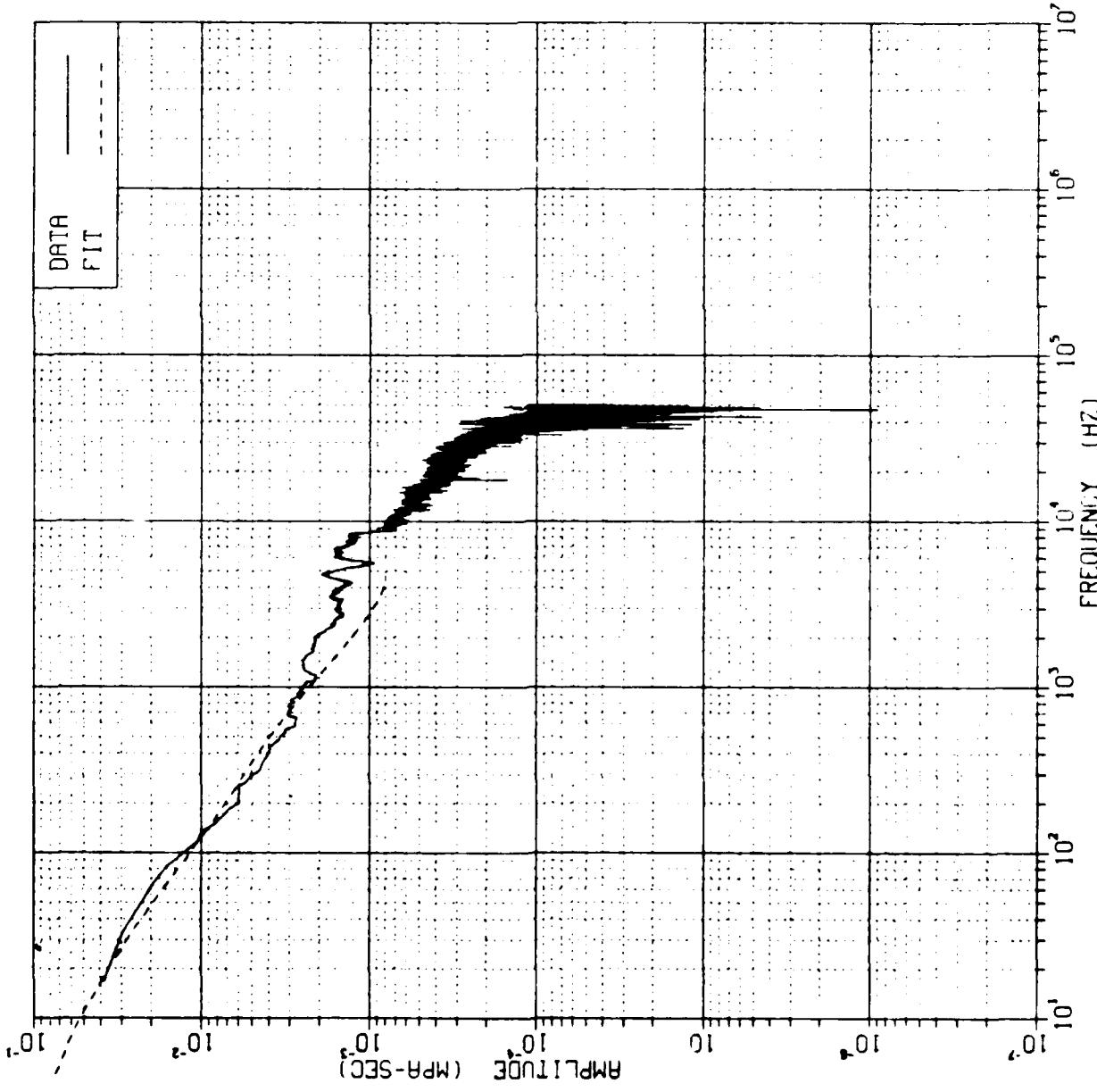


Figure 60

0.35 KBAR HEST 418  
WITH FOURFIT SPEICHER-BRODE

PRESSURE HISTORY

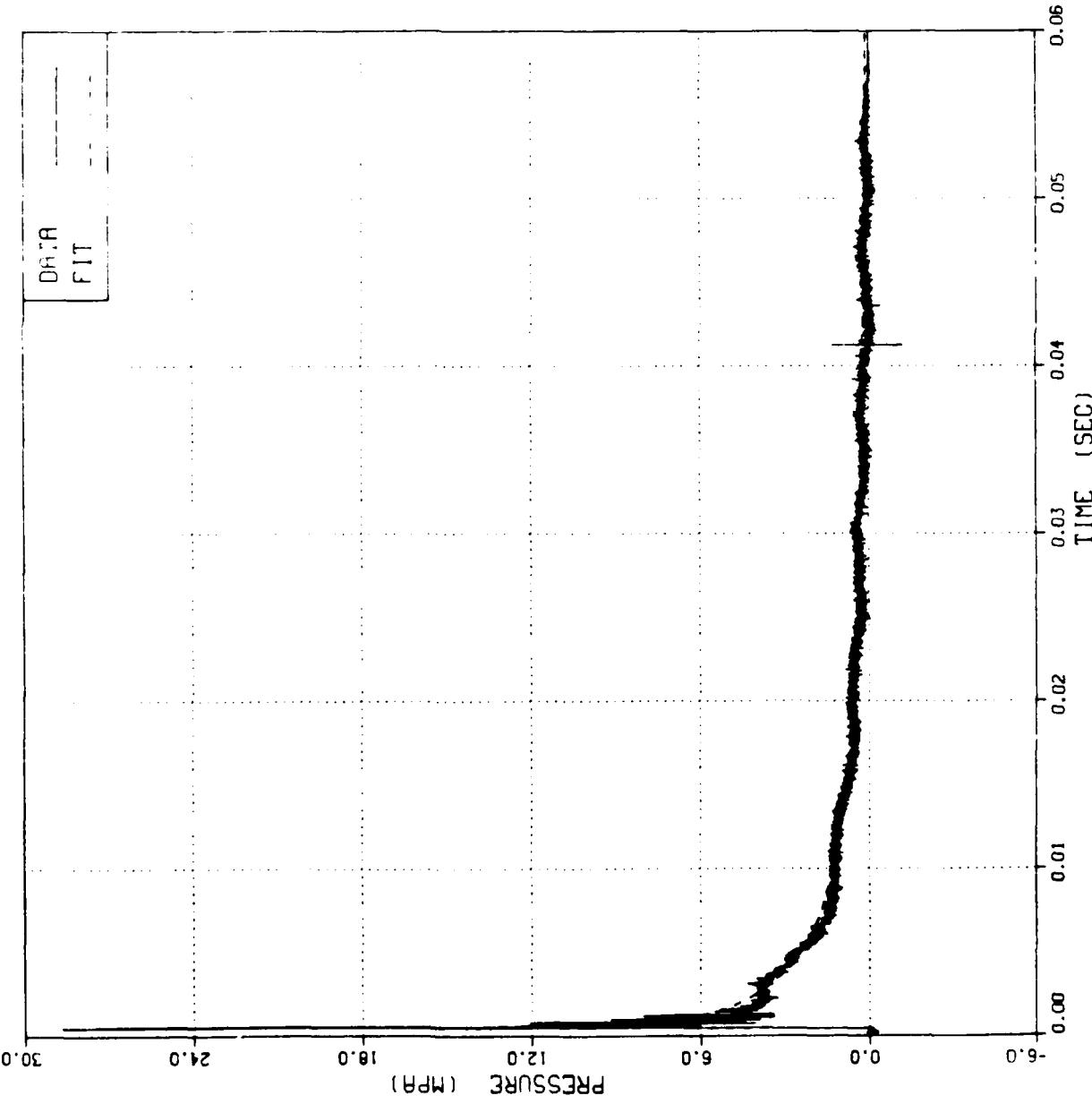


Figure 61  
FOURFIT automated fit to 0.35  
KBAR HEST record 418:  
pressure history comparison.

0.35 KBAR HEST 418  
WITH FOURFIT SPEICHER-BRODE

IMPULSE HISTORY

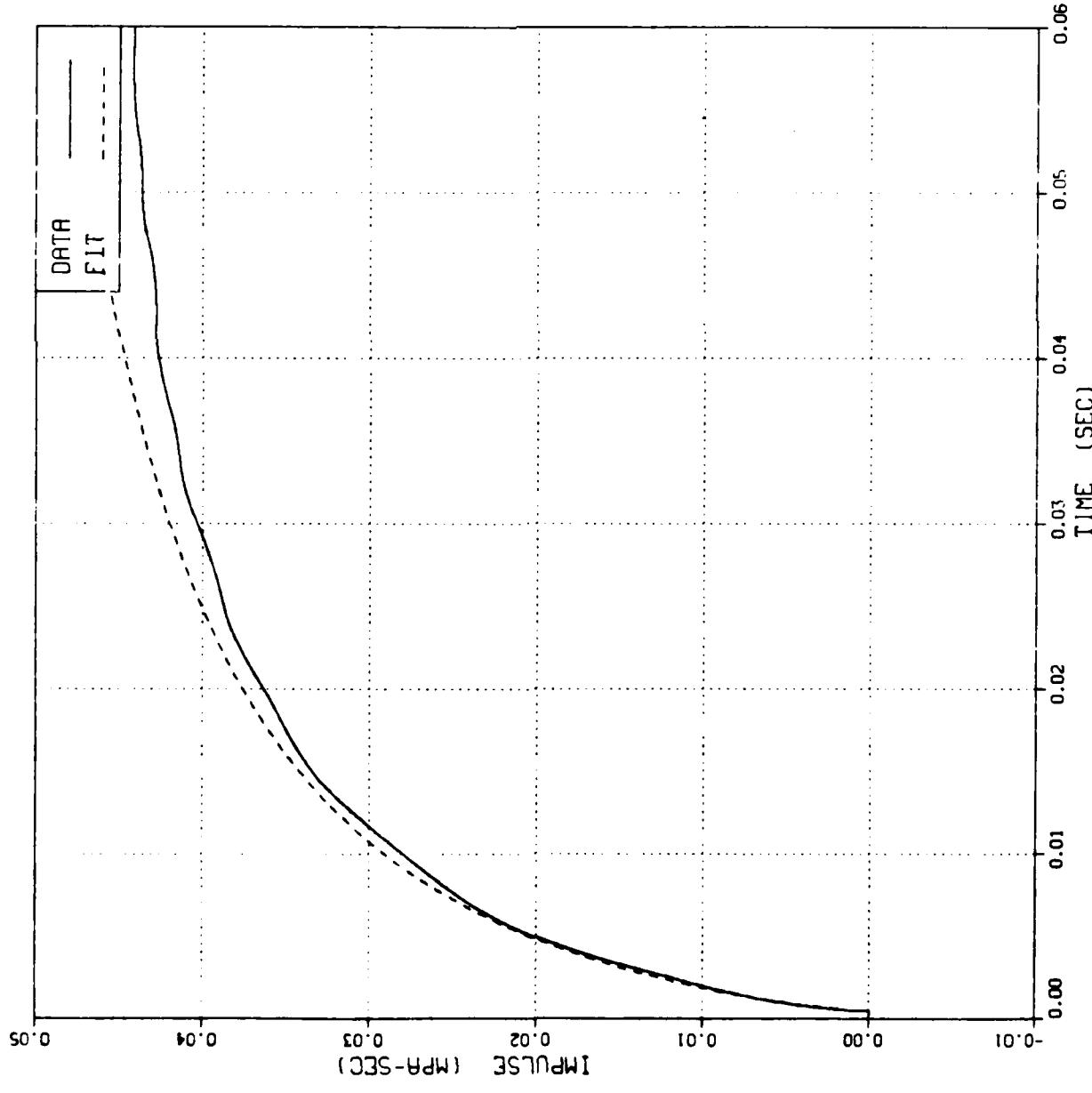


Figure 62

FOURFIT automated fit to 0.35  
KBAR HEST record 418: impulse  
history comparison.

0.35 KBAR HEST 418  
WITH FOURFIT SPEICHER-BRODE

FOURIER AMPLITUDE SPECTRUM

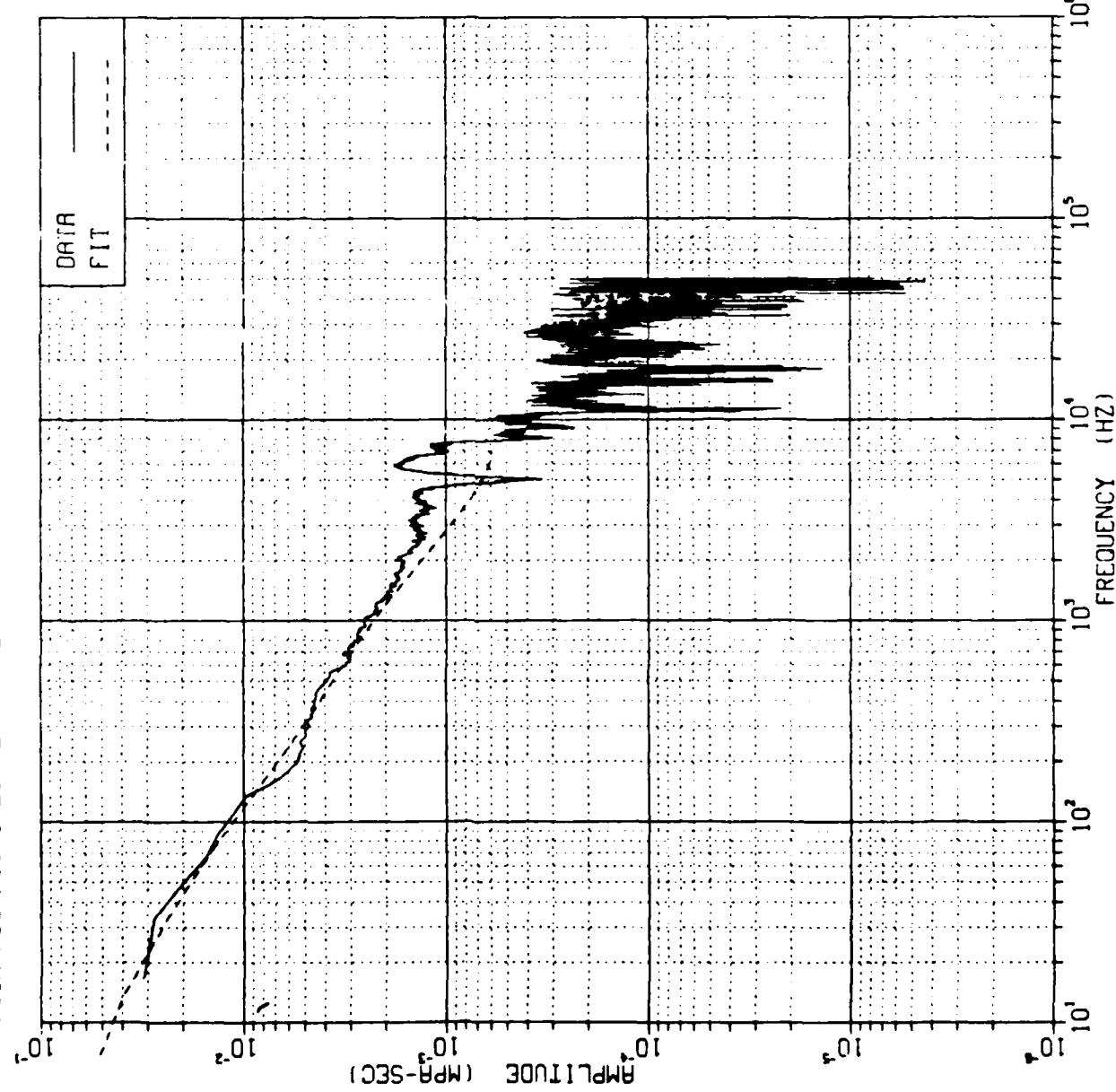
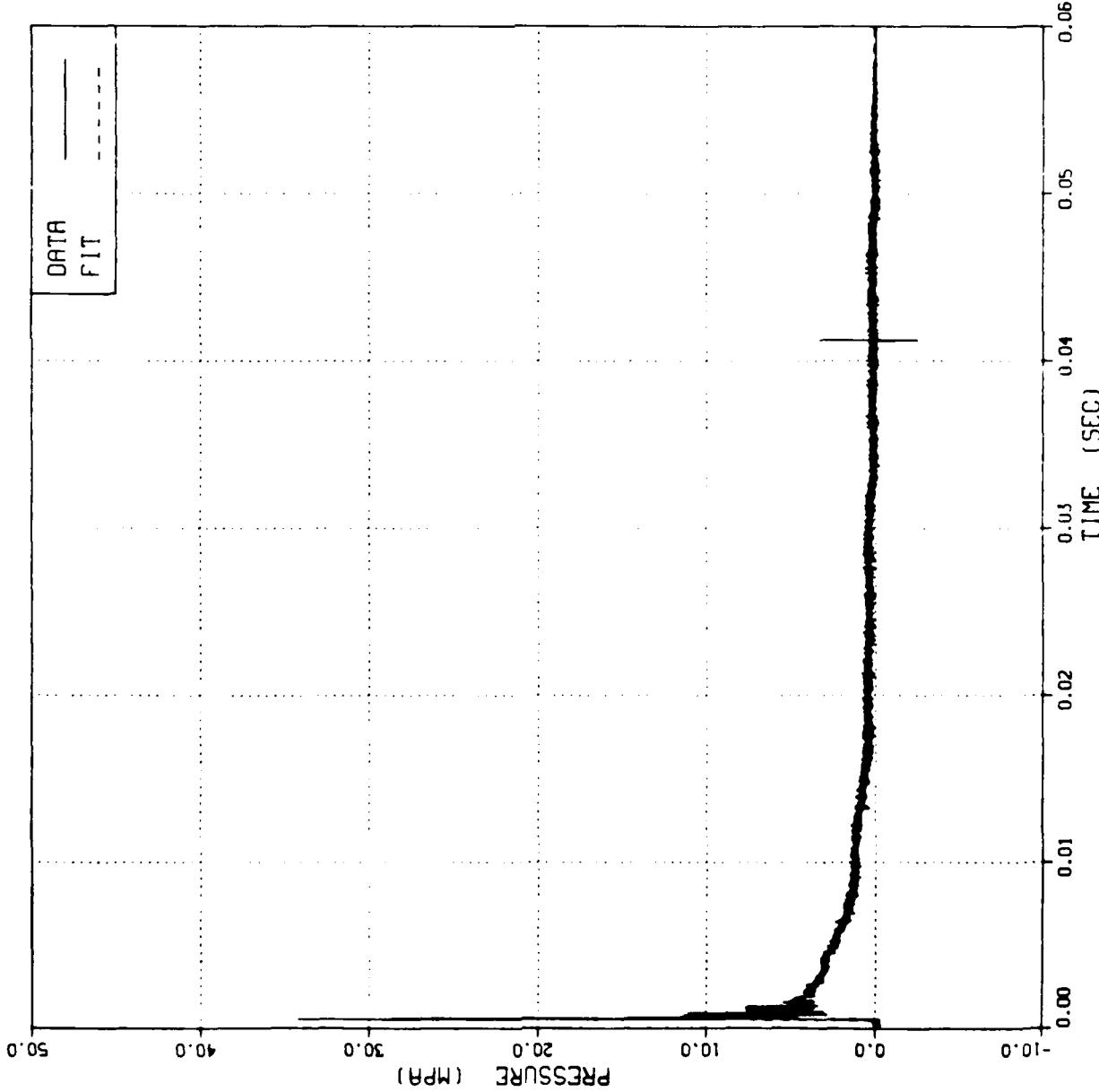


Figure 63

0.35 KBAR HEST 419  
WITH FOURFIT SPEICHER-BRODE

PRESSURE HISTORY



0.35 KBAR HEST 419  
WITH FOURFIT SPEICHER-BRODE

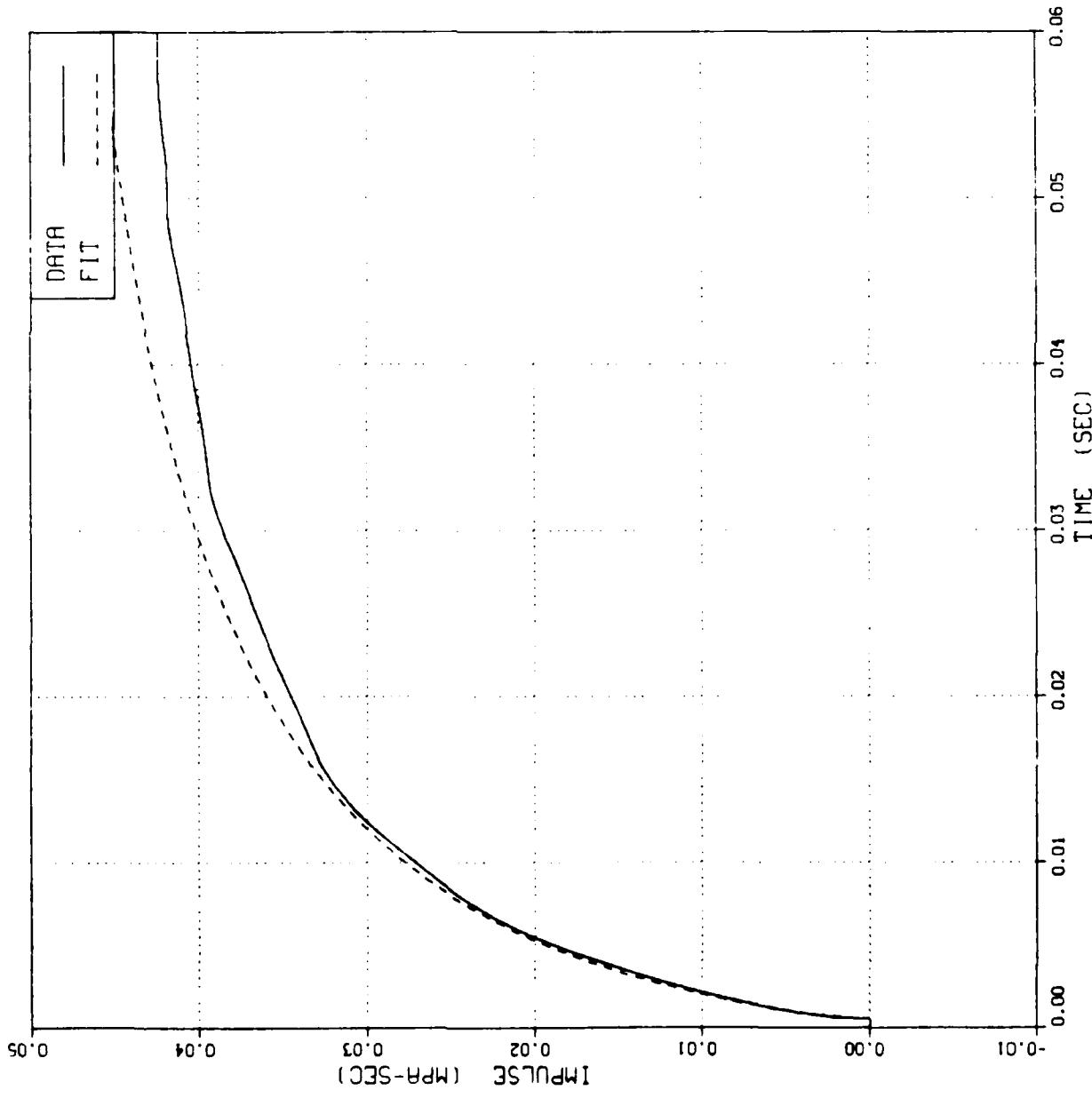


Figure 65

FOURFIT automated fit to 0.35  
KBAR HEST record 419: impulse  
history comparison.

0.35 KBAR HEST 419  
WITH FOURFIT SPEICHER-BRODE

FOURIER AMPLITUDE SPECTRUM

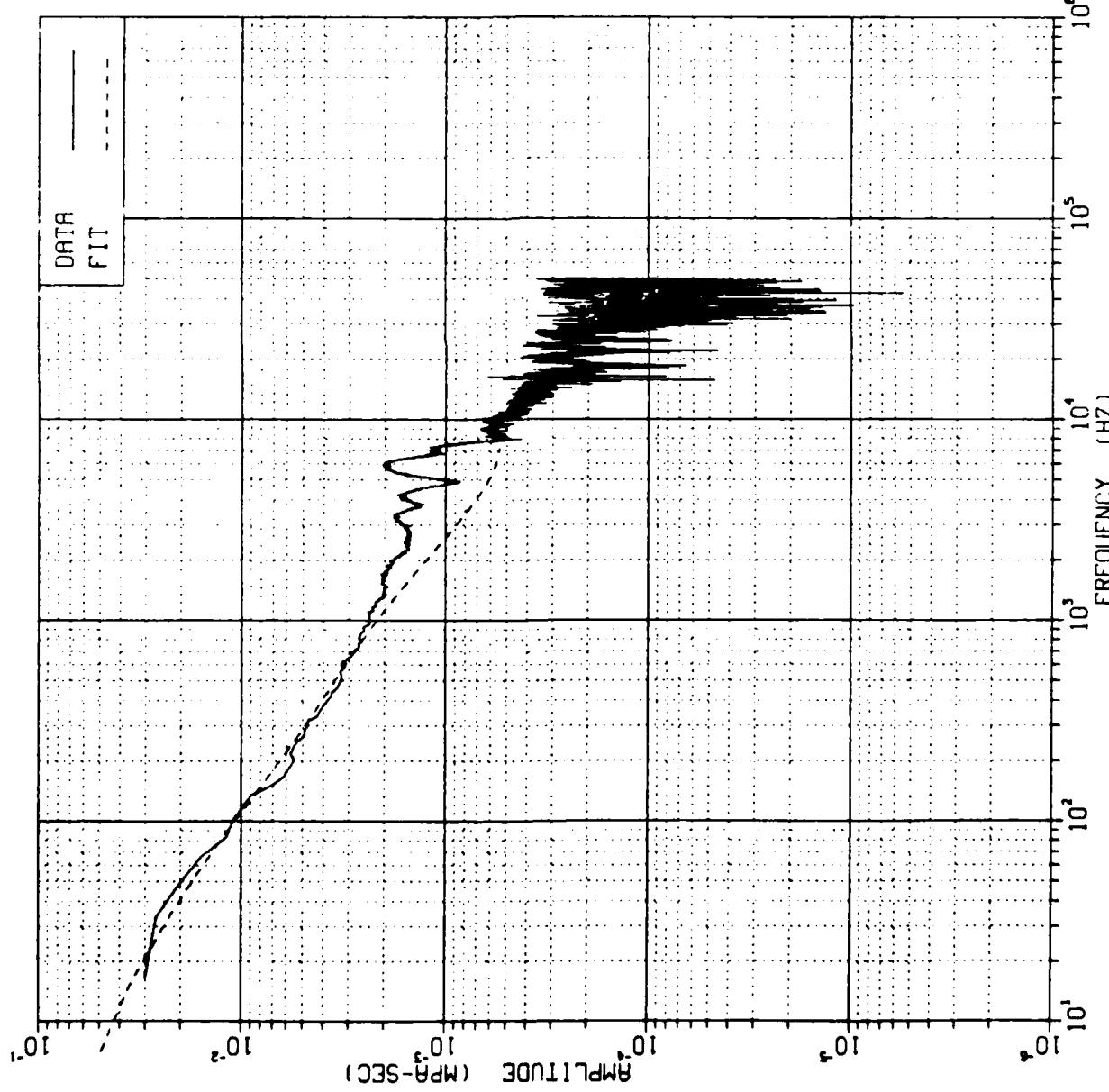
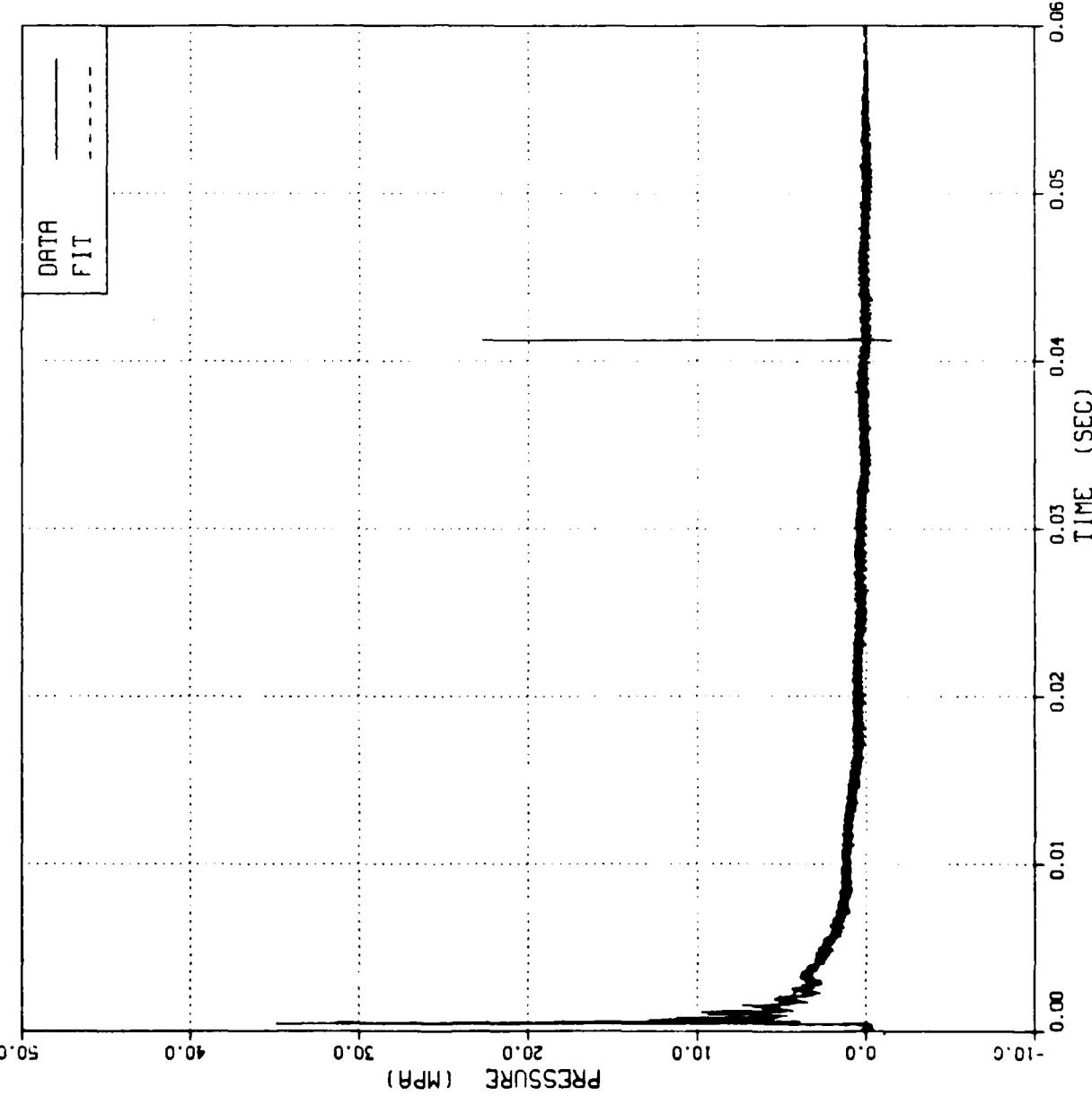


Figure 66

FOURFIT automated fit to 0.35  
KBAR HEST record 419: Fourier  
amplitude spectrum comparison.

0.35 KBAR HEST 54  
WITH FOURFIT SPEICHER-BRODE

PRESSURE HISTORY



0.35 KBAR HEST 54  
WITH FOURFIT SPEICHER-BRODE

IMPULSE HISTORY

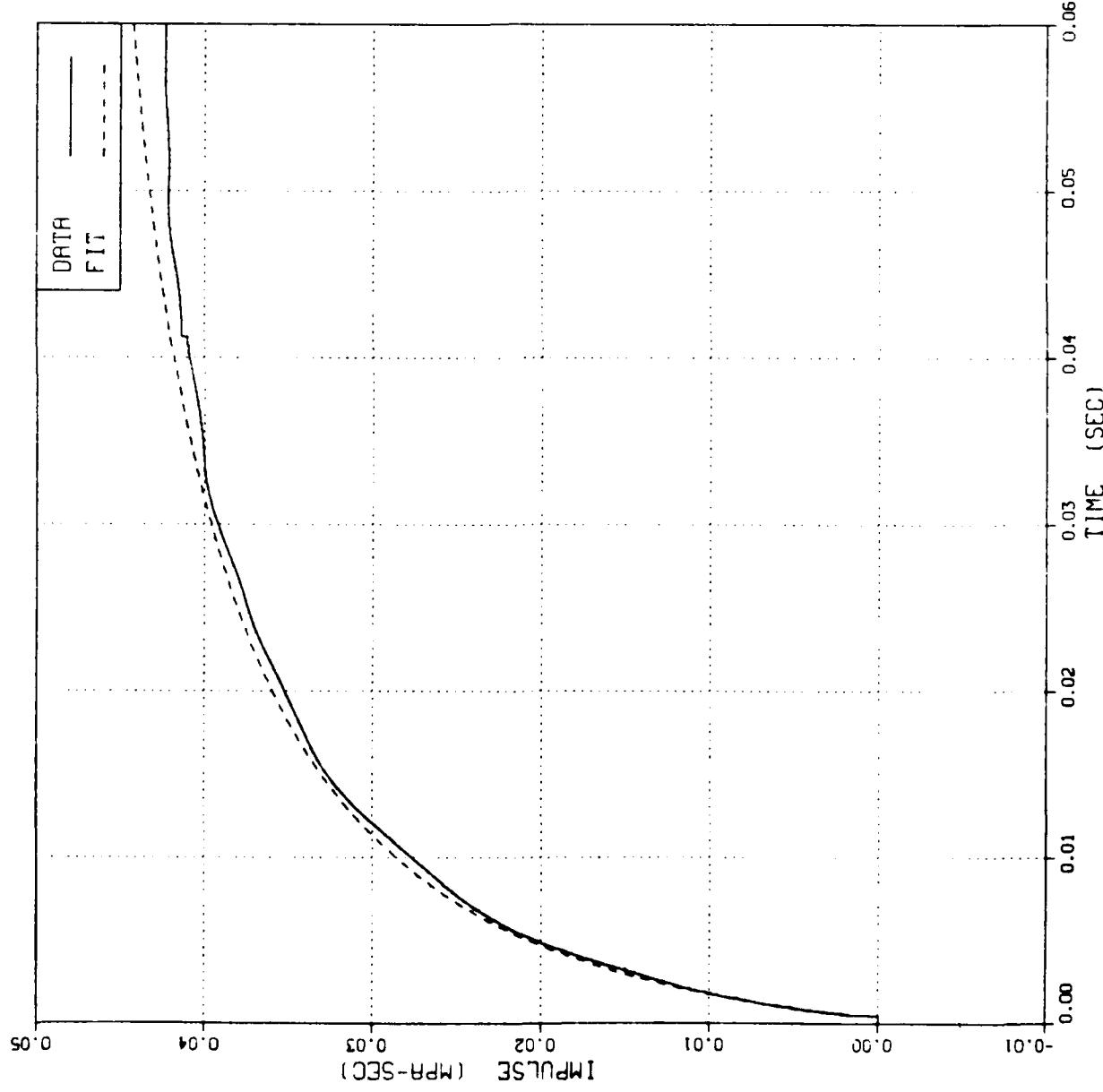


Figure 68

FOURFIT automated fit to 0.35  
KBAR HEST record 54: impulse  
history comparison.

0.35 KBAR HEST 54  
WITH FOURFIT SPEICHER-BRODE

FOURIER AMPLITUDE SPECTRUM

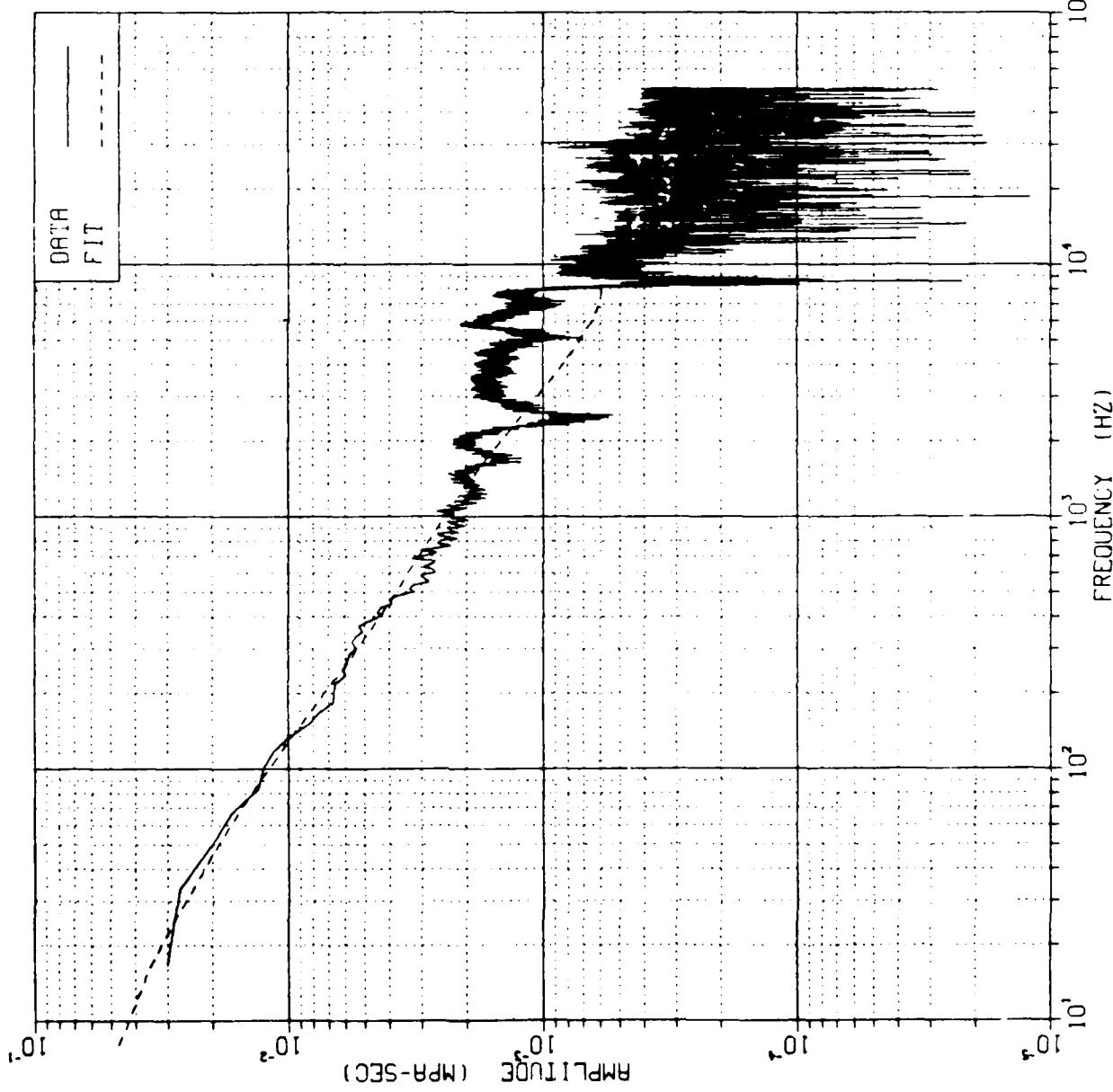
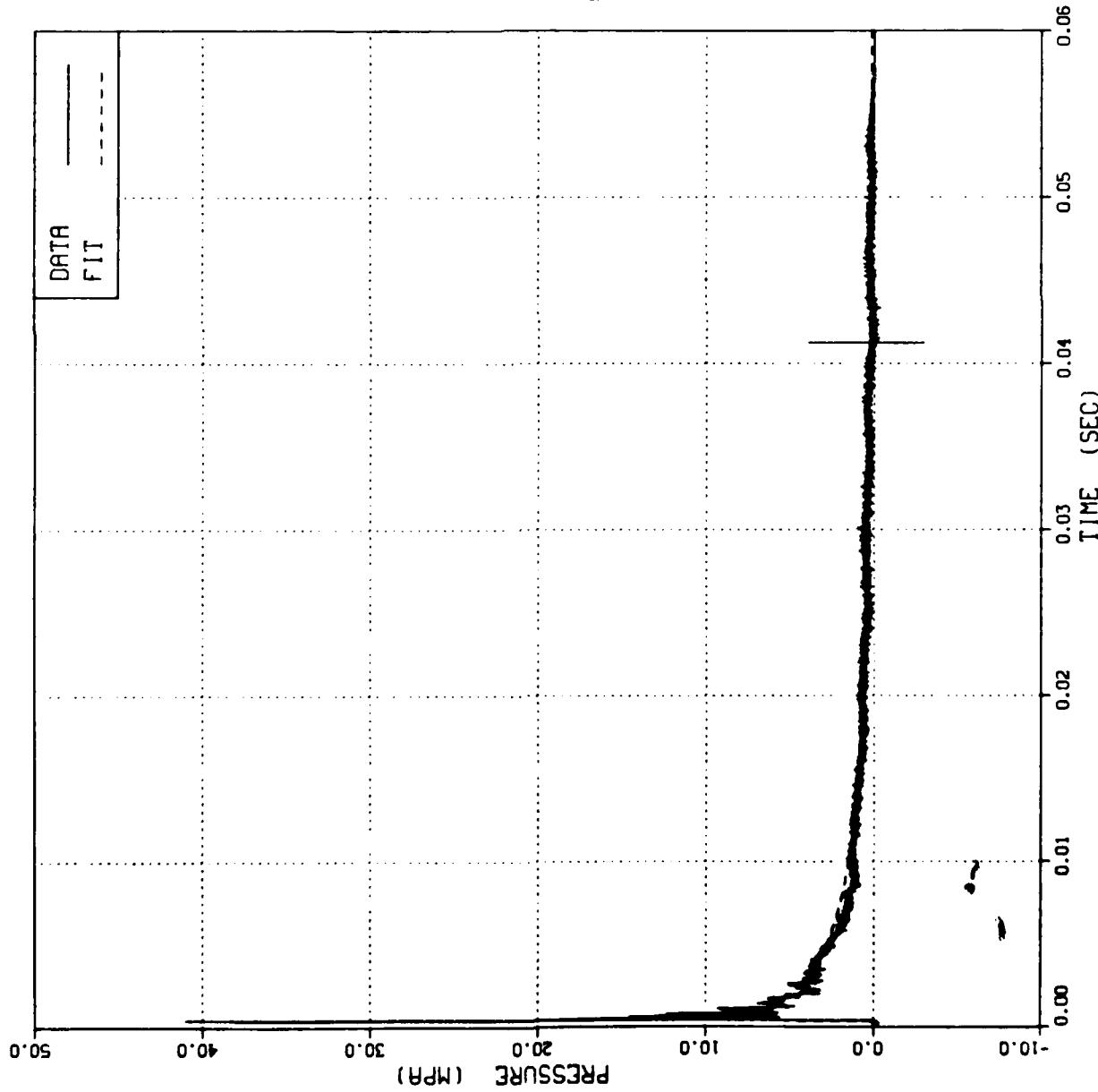


Figure 69

FOURFIT automated fit to 0.35  
KBAR HEST record 54: Fourier  
amplitude spectrum comparison.

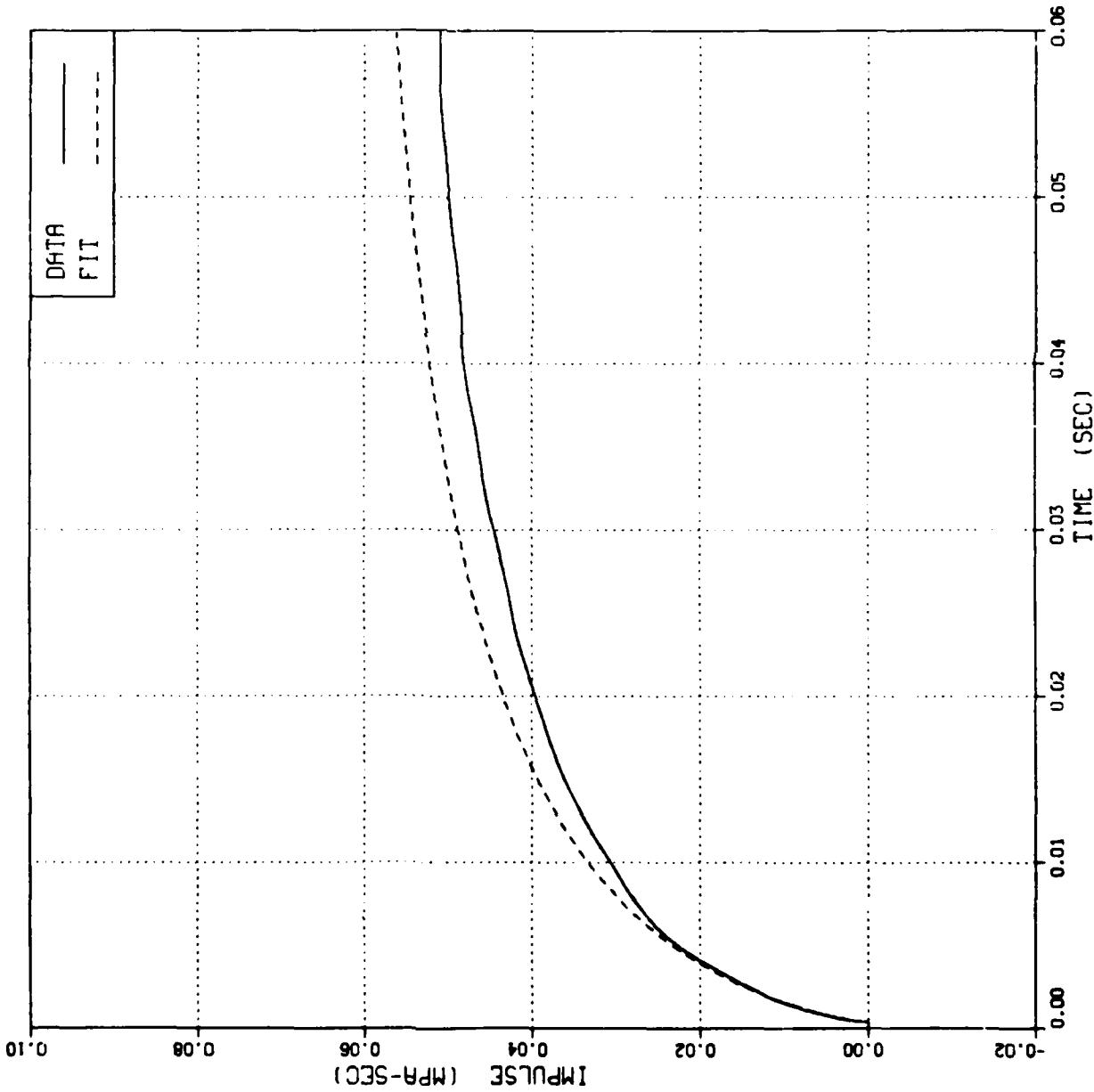
0.35 KBAR HEST 55  
WITH FOURFIT SPEICHER-BRODE

PRESSURE HISTORY



0.35 KBAR HEST 55  
WITH FOURFIT SPEICHER-BRODE

IMPULSE HISTORY



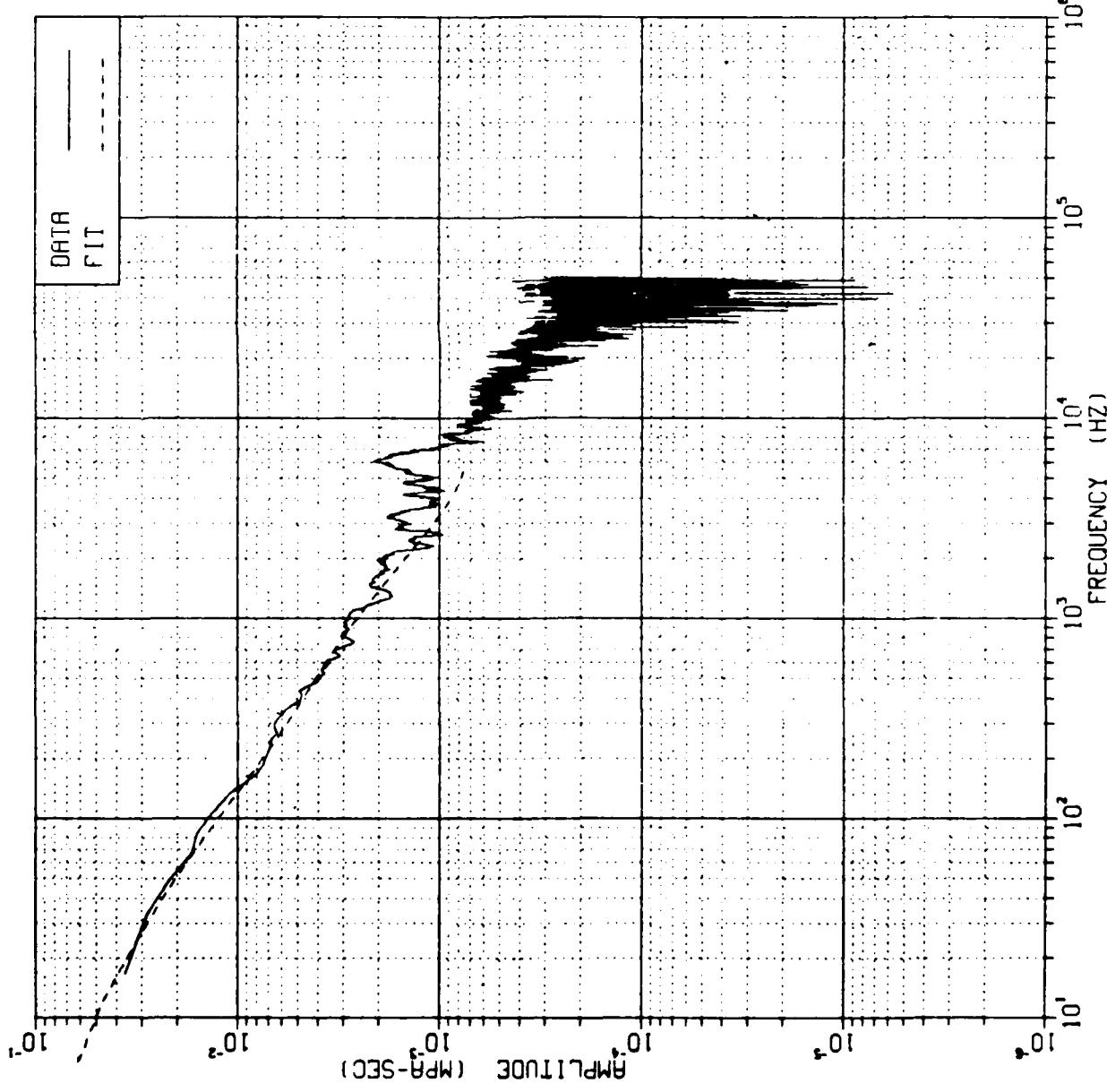
YIELD (KT) -	1.23
PSO (MPA) -	16.61
RANGE (KM) -	0.03726
POS. PHASE (SEC) -	0.16835
T0R (SEC) -	0.000378
LOW PASS FID (HZ) -	2000.

Figure 71

FOURFIT automated fit to 0.35  
KBAR HEST record 55: impulse  
history comparison.

0.35 KBAR HEST 55  
WITH FOURFIT SPEICHER-BRODE

FOURIER AMPLITUDE SPECTRUM

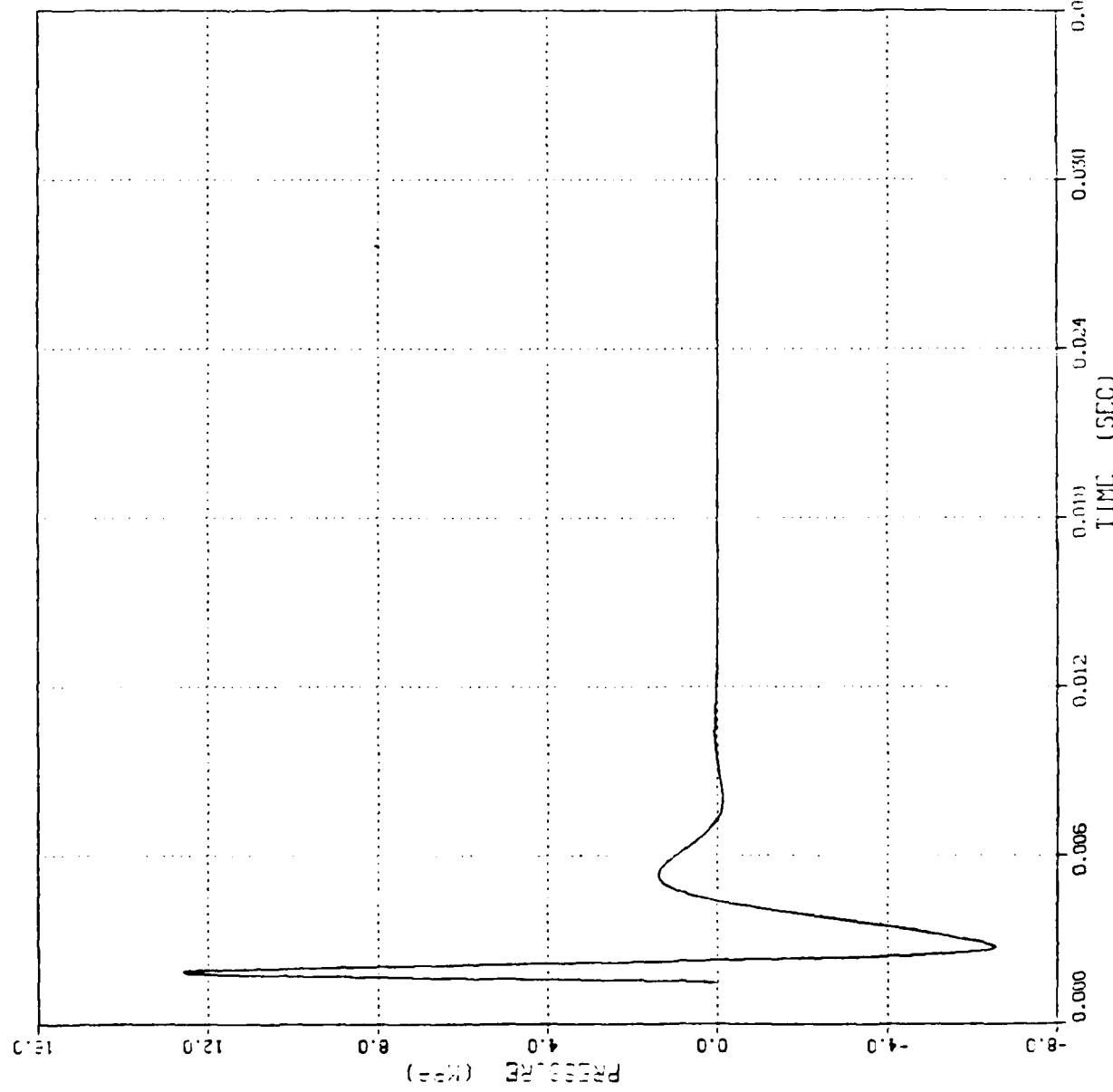


DATA	FIT
YIELD (KT) -	1.23
PS0 (MPA) -	16.61
RANGE (KM) -	0.03726
POS. PHASE (SEC) -	0.16835
TOH (SEC) -	0.00378
LOW PASS FID (HZ) -	2000.

Figure 72

FOURFIT automated fit to 0.35  
KBAR HEST Record 55: Fourier  
amplitude spectrum comparison.

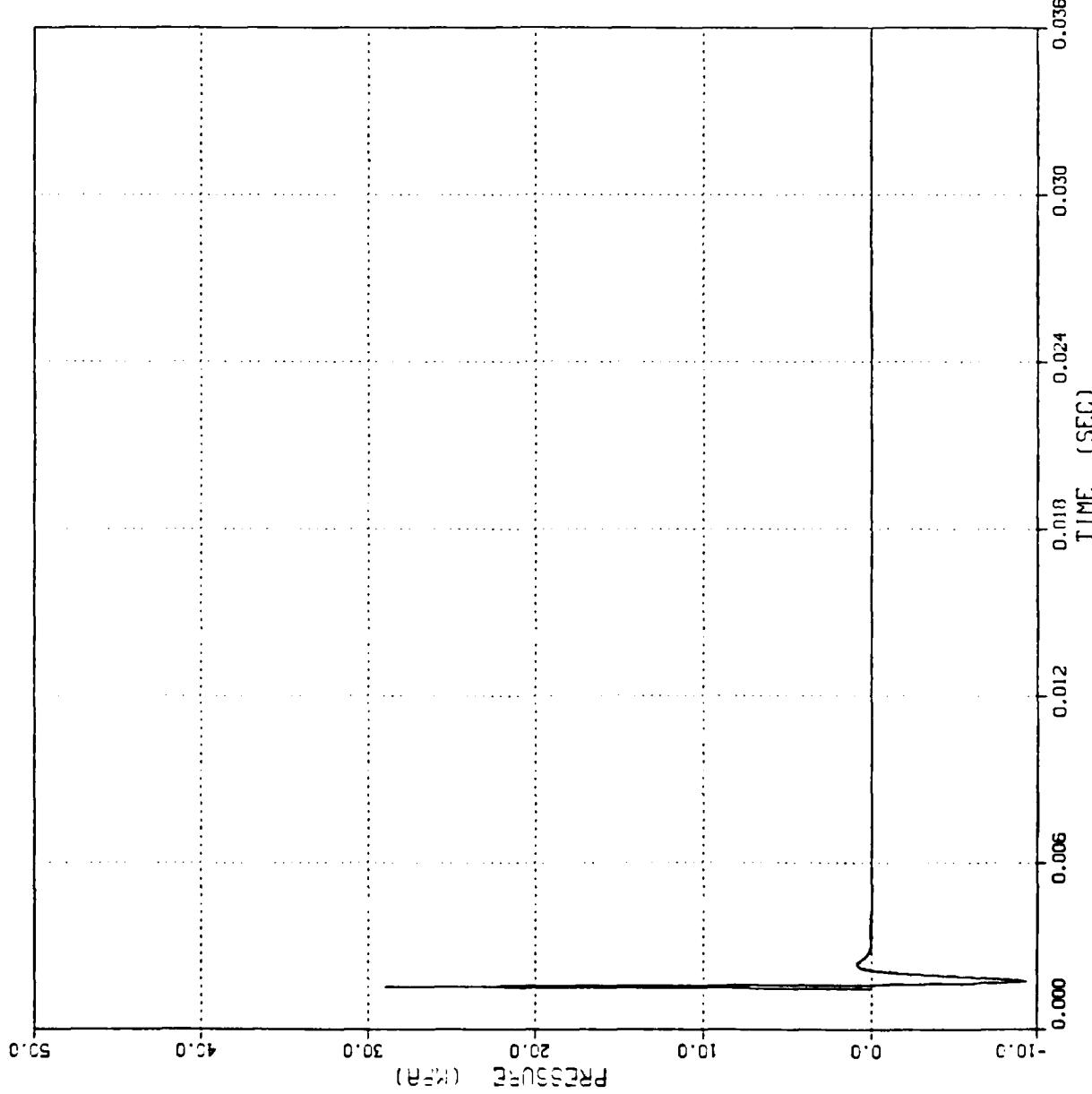
CALCULATED SPEICHER-BRODE PRESSURE HISTORY



YIELD (KT) - 0.87  
 PSO (MPa) - 39.60  
 RANGE (KM) - 0.02475  
 POS. PHASE (SEC) - 0.14297  
 TOA (SEC) - 0.00153

Band pass filtered (FL0 = 200.,  
 FHI = 1000.) Speicher-Brode  
 ( $W = 0.87$  KT,  $P_{SO} = 39.60$  MPa)  
 pressure history.

CALCULATED SPEICHER-BRODE PRESSURE HISTORY



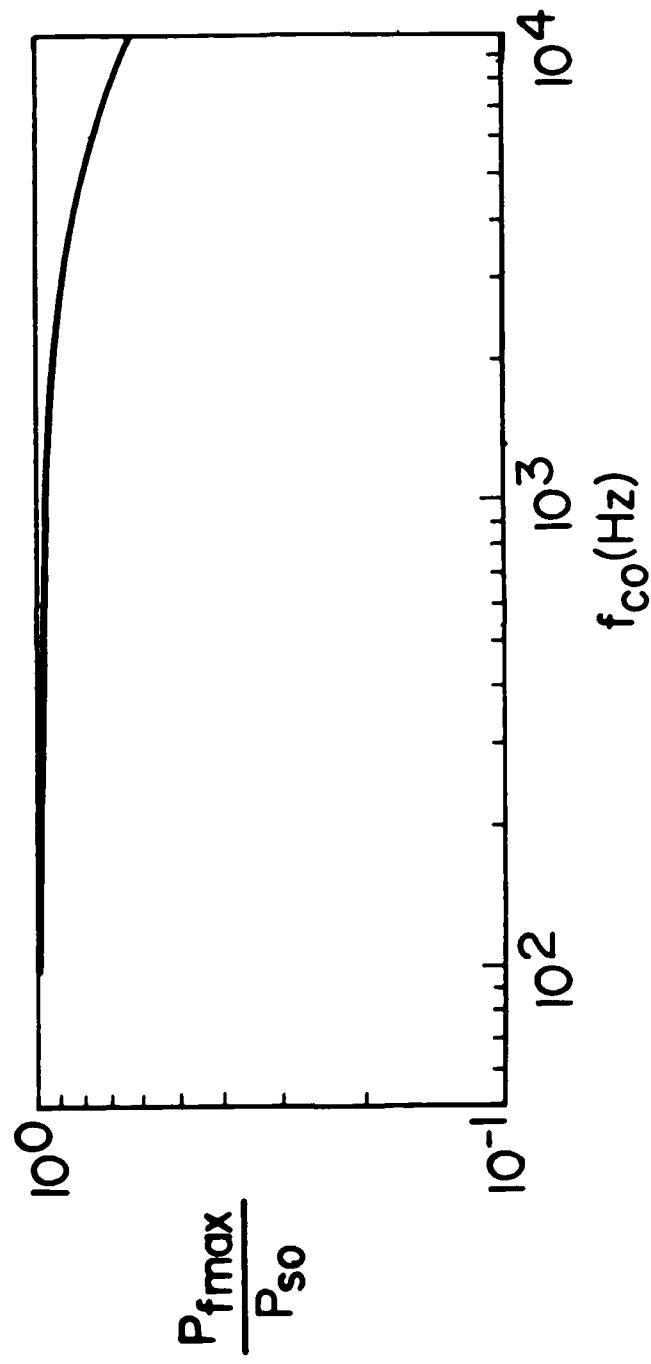
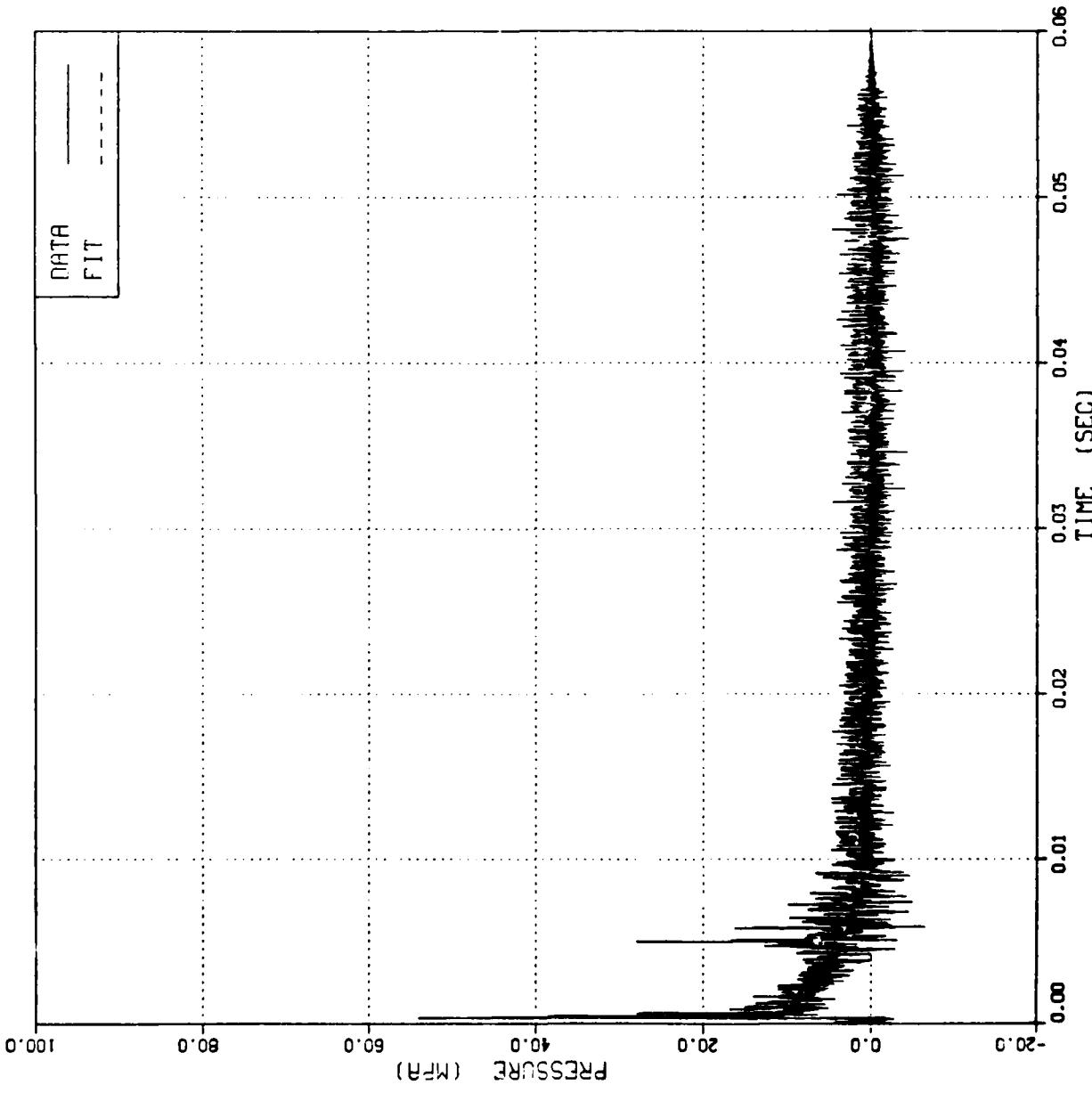


Figure 75. Effect of high pass filter on peak Speicher-Brode overpressure.

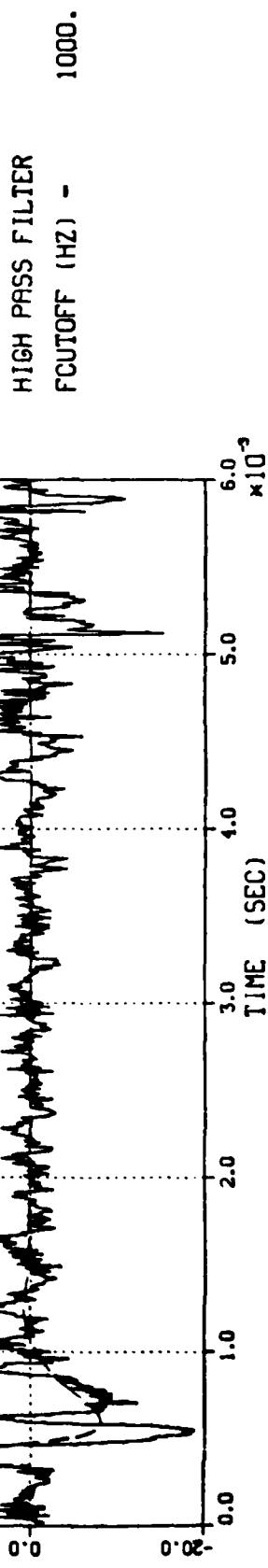
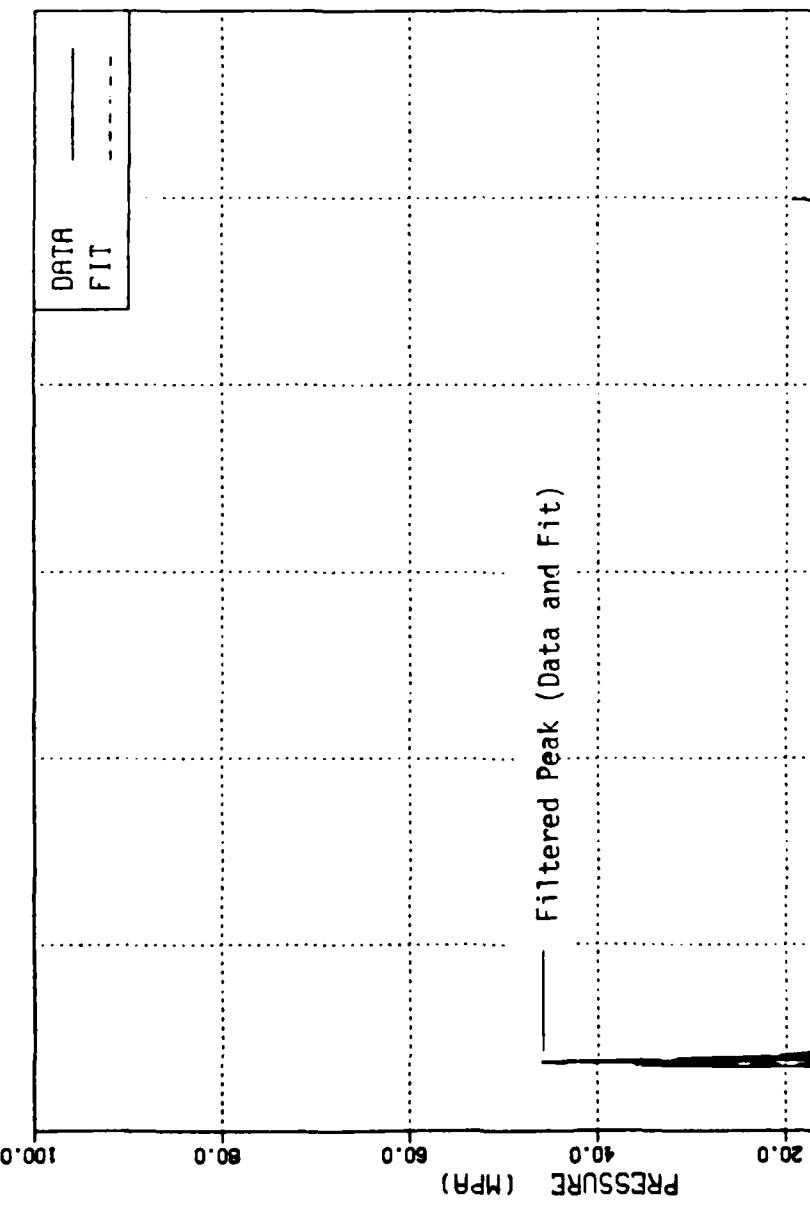
0.35 KBAR DISC HEST AB-5  
WITH FOURFIT SPEICHER-BRUDER

PRESSURE HISTORY



0.35 KBAR DISC HEST AB-5  
WITH FOURFIT SPEICHER-BRODE

PRESSURE HISTORY



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